

From Natural Evolution to Artificial Intelligence

Difference and Repetition as Creative Process



Lecture 16 | Generative Design

Week 5 – Design Thinking and Material Practices

Coexistent Perspectives (ADAA7000)

From Natural Evolution to
Artificial Intelligence

Lecture Aims

Generative Design

Difference and Repetition as
Creative Process

- The lecture explores how generative design and AI use **difference** and **repetition** to foster creativity and innovation.
- It highlights the shared foundations and practical uses of these fields, inspired by **natural processes, emergence, and complexity.**
- The lecture examines how **algorithmic generation, iteration, constraints, and feedback loops** lead to novel solutions.
- It discusses future **synergies between generative design and AI**, showing their potential to revolutionize architecture, design, art, and entertainment.



Tyler Hobbs, *Holmberg 2*, 2018

From Order within Chaos to Generative Design

*From describing natural systems to
generating new ones*

- In *Order within Chaos* Lecture — how patterns, rhythms, and forms emerge through natural systems.
- This lecture explores how we move from **observation to generation** — from analysing emergent order to producing it algorithmically.
- Generative Design extends **morphogenesis** and **complexity theory** into creative practice through computation, simulation, and iteration.
- In doing so, it asks: *What happens when creativity itself becomes procedural, coded, and evolutionary?*



Neri Oxman, Silk Pavillion, 2013

Material Agency in Generative Design

New Materialism and posthuman creativity

- Generative design redistributes **agency** across human, material, and algorithmic systems.
- Design becomes an *intra-action* (Barad), where matter, code, and computation co-produce form.
- Following Bennett's "**vibrant matter**", materials and algorithms are not passive tools but active participants.
- Malabou's **plasticity** offers a bridge — the capacity of form to both *receive* and *give* form — a key trait of generative processes.

"Matter is not a substrate but an agent, a generative field of relations."

— Jane Bennett, *Vibrant Matter* (2010)



Tyler Hobbs, *Fidenza 313*, 2021

From Optimisation to Imagination

Shifting paradigms in generative practice

- Early generative design sought **optimisation** — structural efficiency, minimal waste, and functional perfection.
- Contemporary practice embraces **speculation and emergence** — designing systems that evolve unexpected outcomes.
- The designer's role moves from *author* to *curator*, steering iterative processes rather than dictating form.
- Generative systems thus become **imaginative ecologies**, balancing human intention with algorithmic discovery.

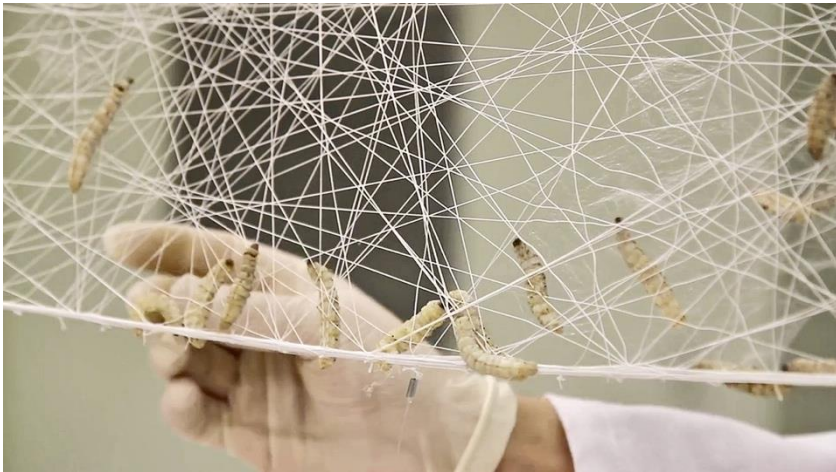
“Design is no longer about the object but the conditions for its becoming.”

- paraphrasing Jack Burnham, *Systems Esthetics* (1968)

Generative Ecosystems

nature → algorithm → design

Generative design mirrors nature's capacity for complexity: not imitation, but co-evolution between the natural, digital, and conceptual realms.



Neri Oxman, Silk Pavillion, 2013

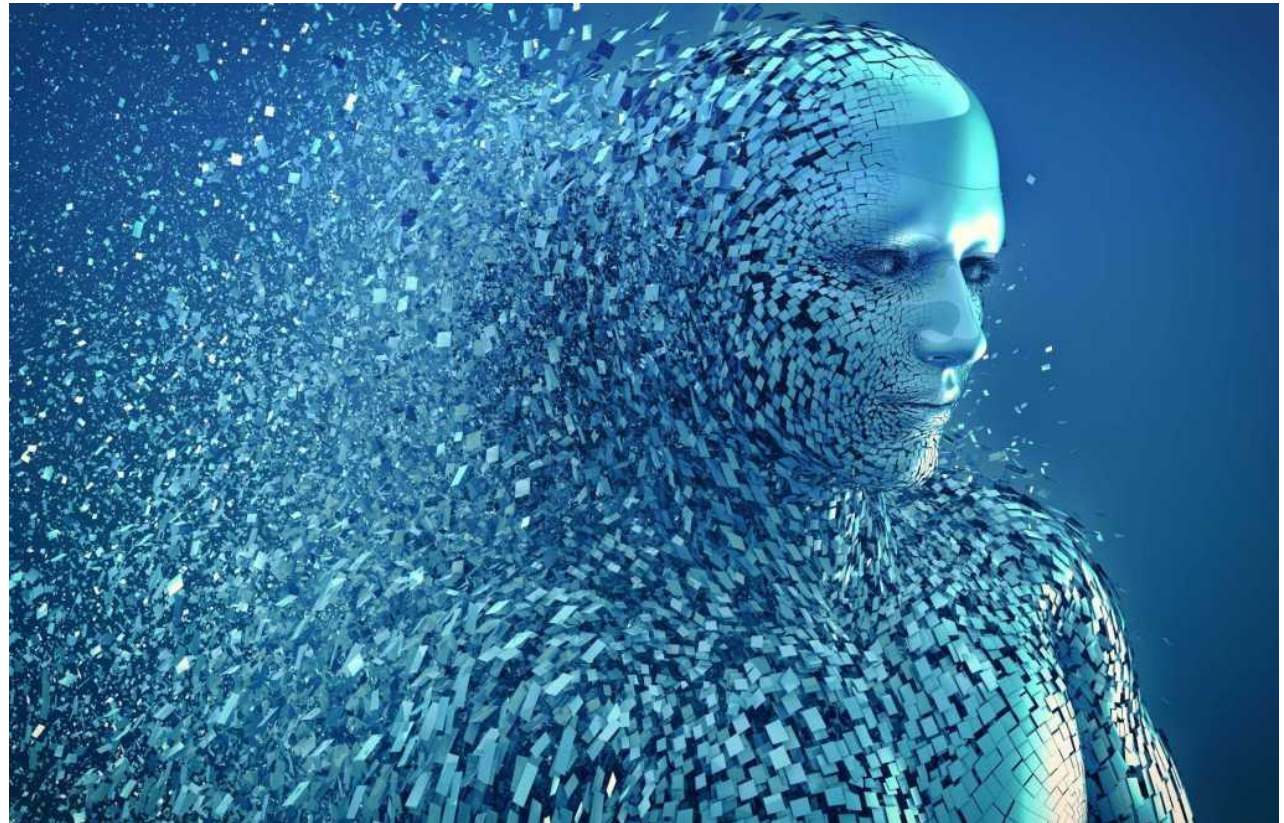
Natural System	Digital System	Conceptual Principle
Mycelium Networks	Neural Networks	Distributed Intelligence
Genetic Variation	Algorithmic Mutation	Evolutionary Diversity
Morphogenesis	Procedural Growth	Emergent Form
Ecological Feedback	Algorithmic Loop	Adaptive Iteration
Environmental Constraint	Parametric Rule	Conditional Design

philosophical shift from **representation** (seeing and describing nature's patterns) to **participation** (working *with* those same generative principles).

The Evolutionary Origins of Generative Design and Generative AI

I think it's quite conceivable that *humanity is just a passing phase in the evolution of intelligence.* You couldn't directly evolve digital intelligence. It would require too much energy and too much careful fabrication. **You need biological intelligence to evolve so that it can create digital intelligence...**

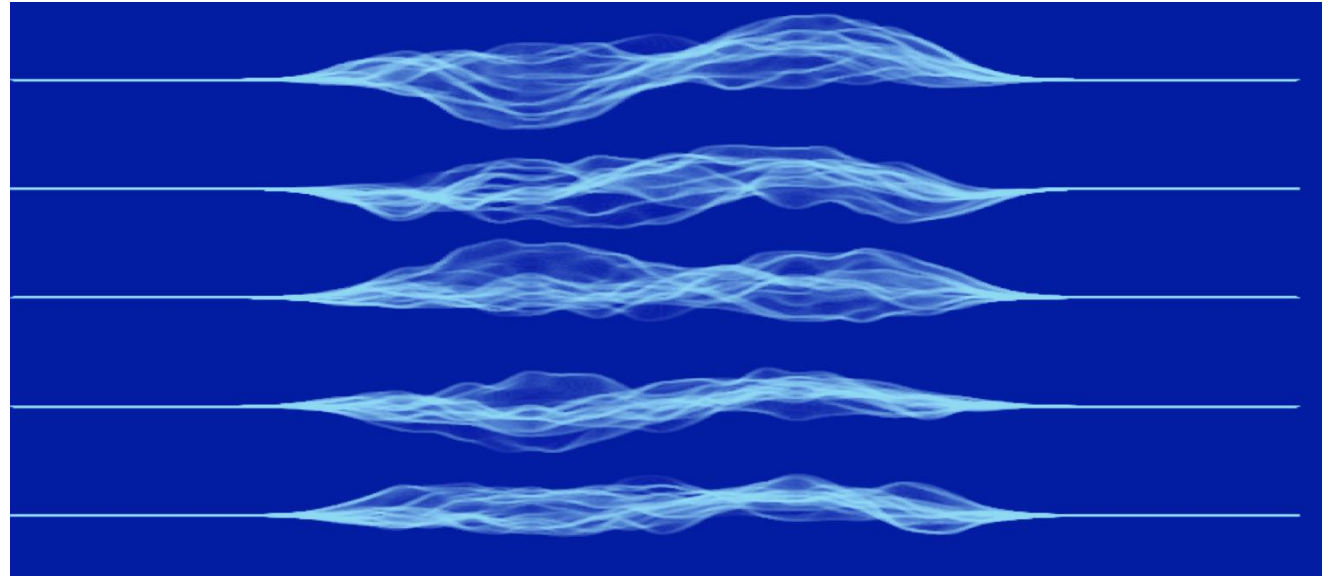
Geoffrey Hinton ('the Godfather of AI')



Biological intelligence evolved to create digital intelligence, which can absorb everything humans have created...

What?

...is generative design



What is Generative Design

a definition

Generative design is an iterative design process that uses software to generate outputs that fulfil a set of constraints iteratively adjusted by a designer.



“generative design is **not** about **designing the building**, it
is about designing the **system that builds** a building”

Lars Hesselgren

systems thinking | thinking systems

We are now in transition from an *object-oriented* to a *systems-oriented* culture. Here change emanates, ***not from things***, but from ***the way things are done***.

Jack Burnham (1968), System Esthetics

Who is a Generative Designer?

a definition

A **generative designer** is a professional who uses computational algorithms and iterative processes to create innovative designs by exploring a vast range of possibilities based on predefined constraints and parameters.

This approach leverages principles from nature, mathematics, and artificial intelligence to optimize and evolve design solutions.

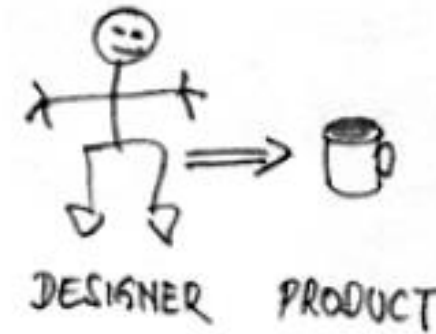


Figure 1: Traditional design approach

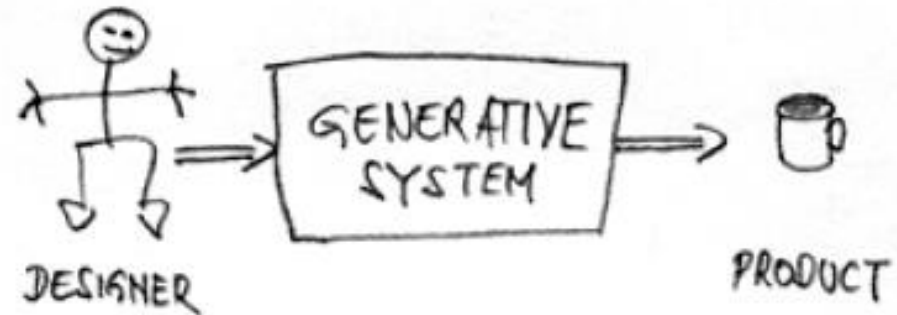
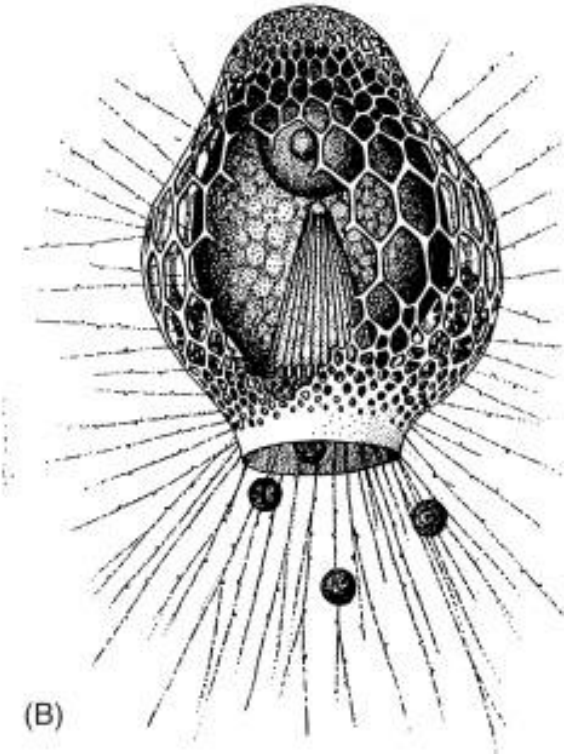
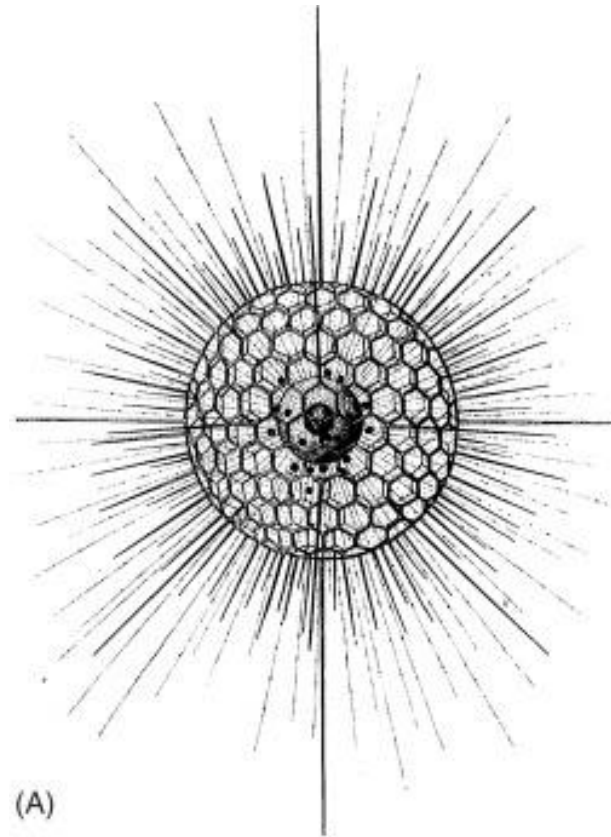


Figure 2: Generative design approach

Generative Design

evolutionary principles and
historical context

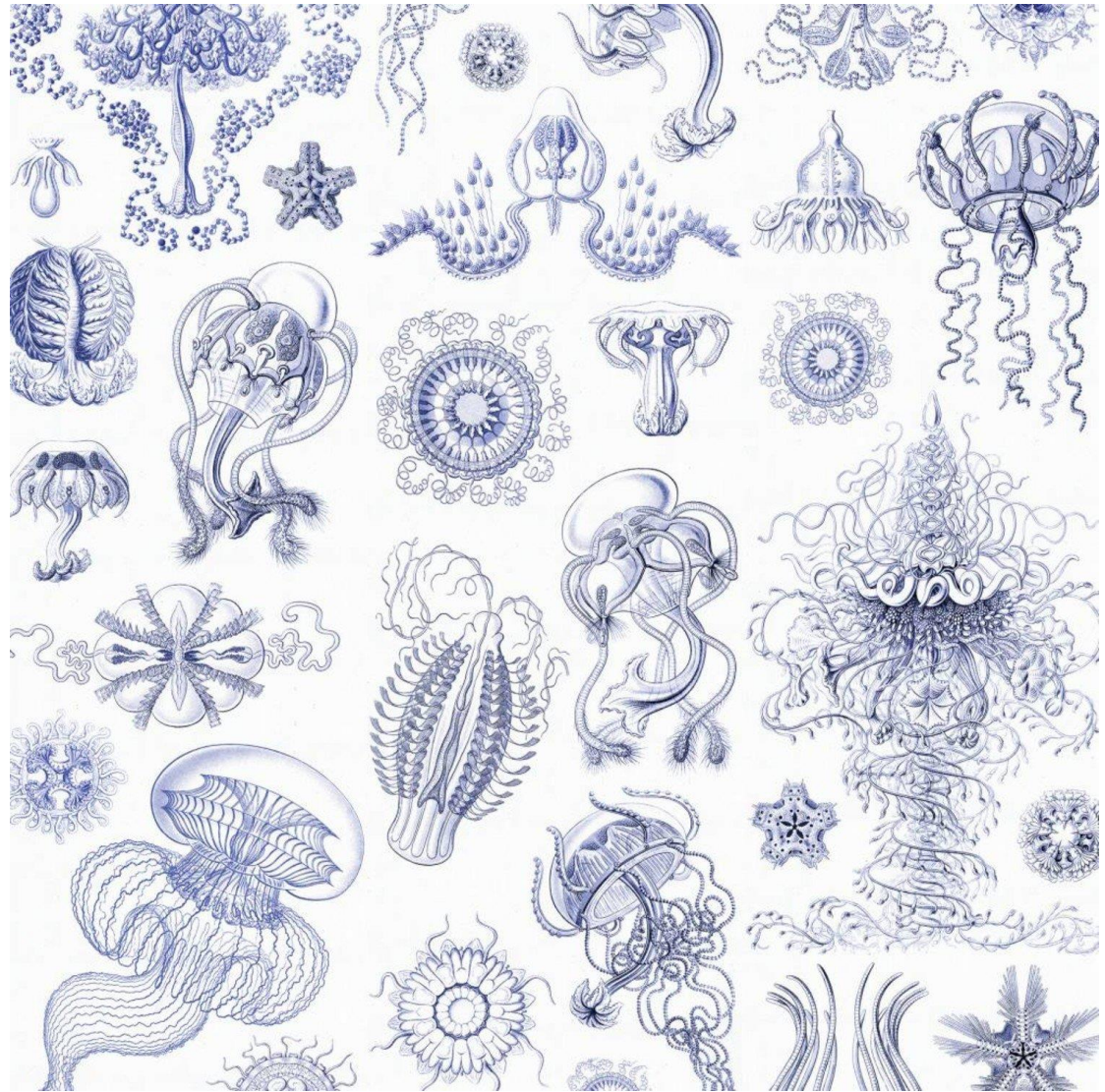


Radiolarians | Ernst Haeckel

Generative Design in Nature

evolutionary principles in design

- Concept of evolution in nature versus design
- Key evolutionary principles: **variation, inheritance, selection and time**
- Case studies of evolutionary design in practice

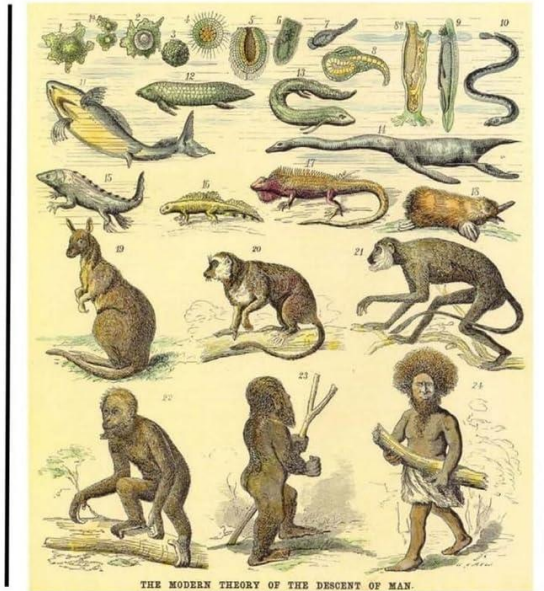


Creative Evolution

By

Henri Bergson

Translated by Arthur Mitchell



form and function

creativity and aesthetics

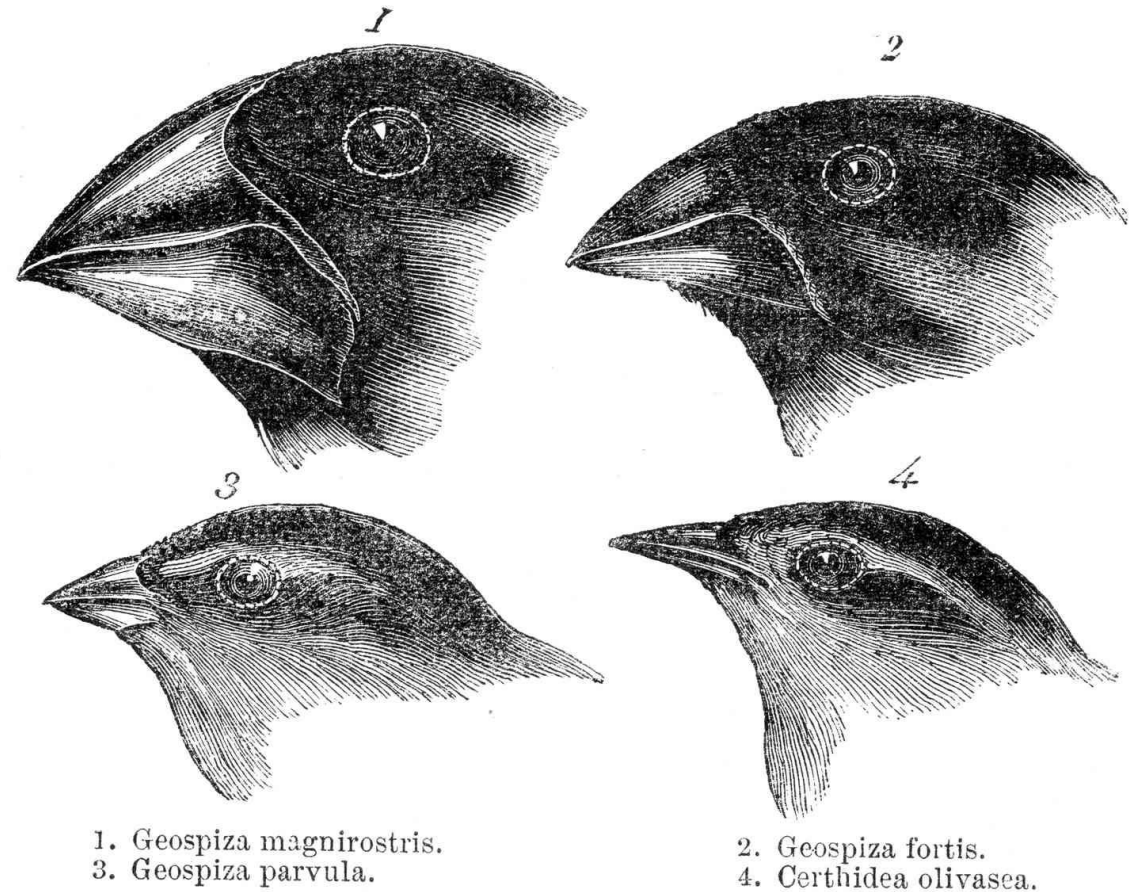
the whole evolutionary process should be seen as the endurance of an **élan vital** (“vital impulse”) that is continually developing and **generating** new forms. **Evolution, in short, is creative, not mechanistic.**

Henri Bergson

Generative Design in Nature

evolutionary principles in design

There are four principles at work in evolution—**variation, inheritance, selection and time.** These are considered the components of the evolutionary mechanism of **natural selection.**



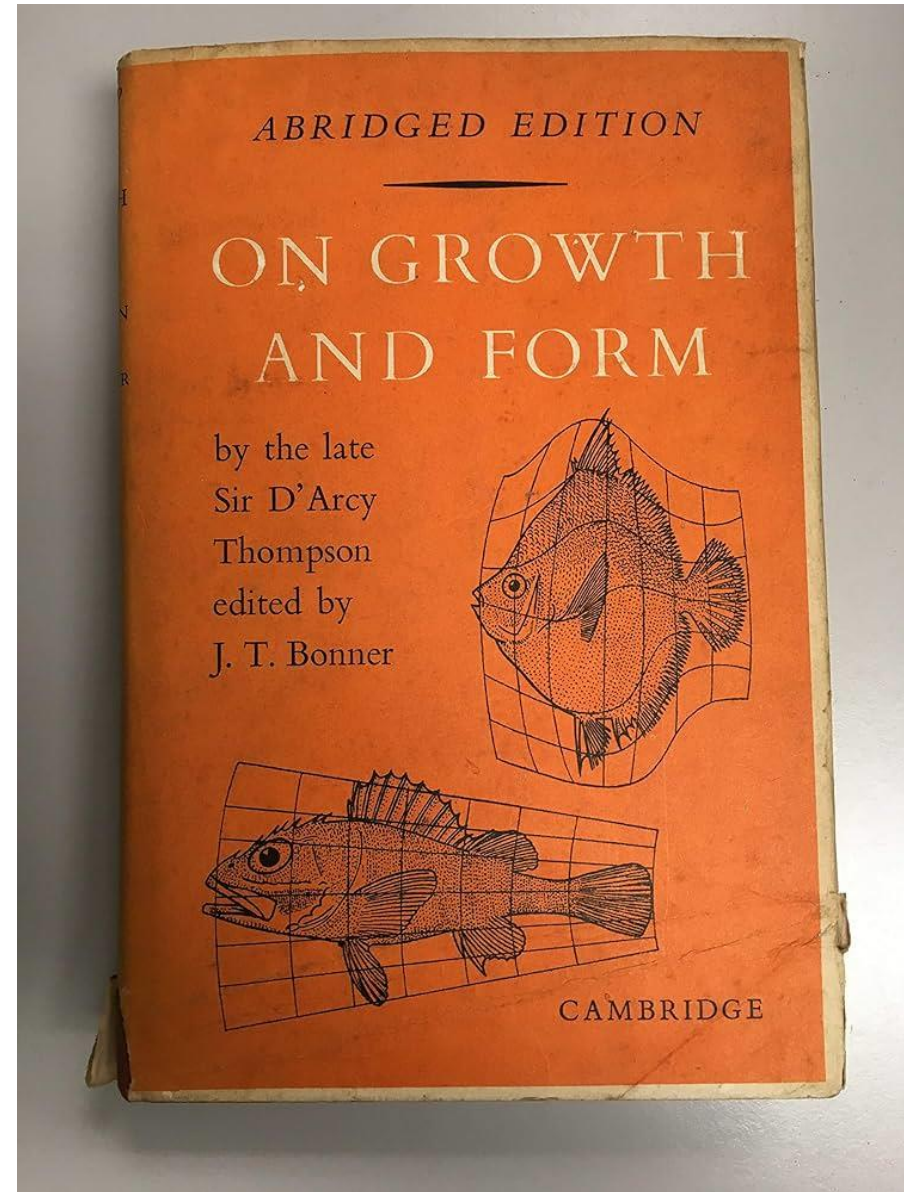
Charles Darwin sketches of four variations in finch beaks from *On the Origin of Species* (1859)

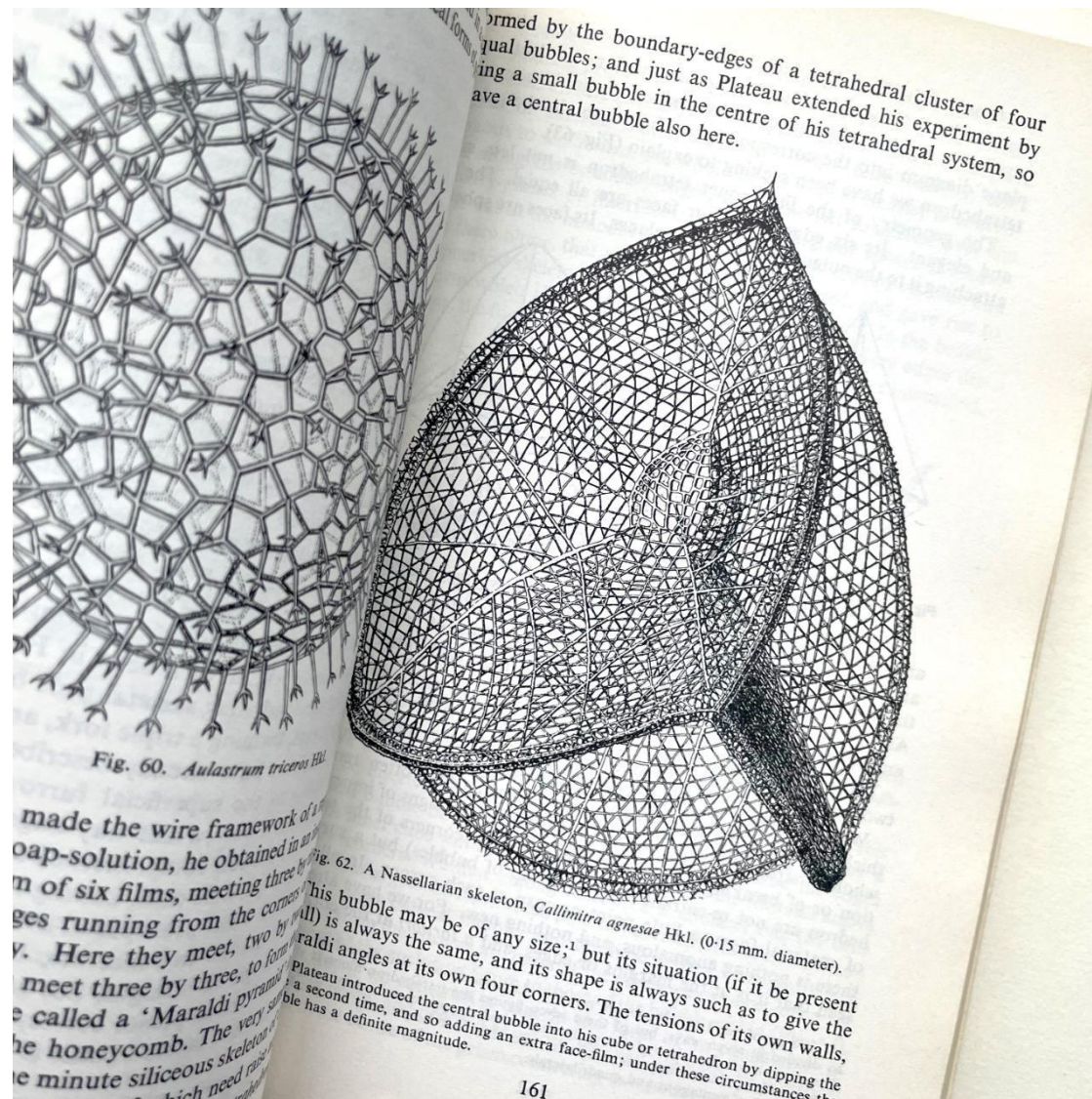
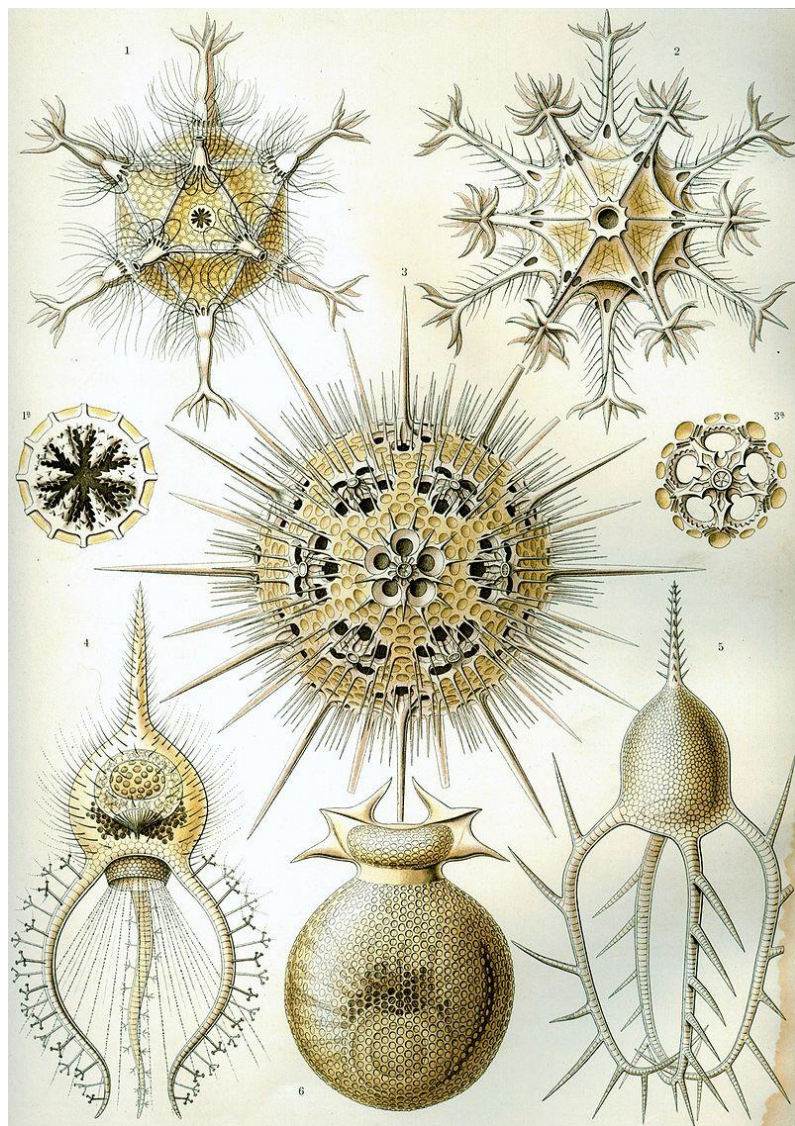
On Growth and Form

D'Arcy Thompson

Mathematical Principles in Nature: Thompson's work demonstrates how mathematical laws underlie the growth and form of natural organisms.

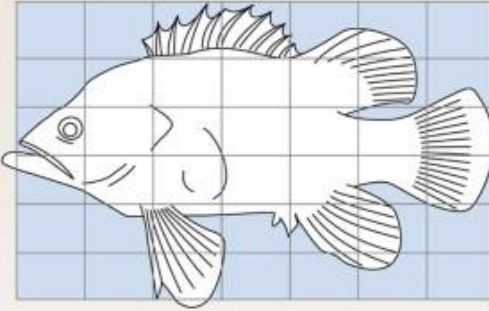
Morphogenesis: The process by which biological forms develop and evolve, driven by physical and mathematical principles.



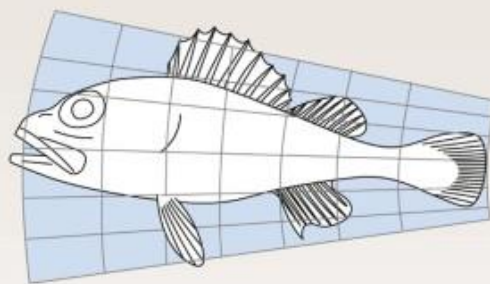


All fish are the same shape if you stretch them?

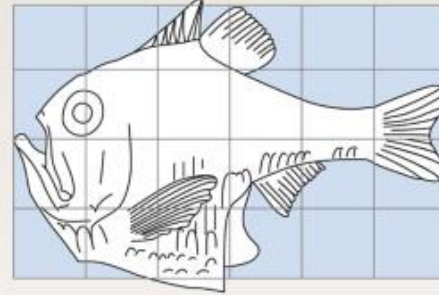
Polyprion



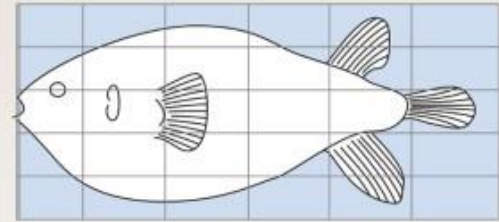
Scorpaena



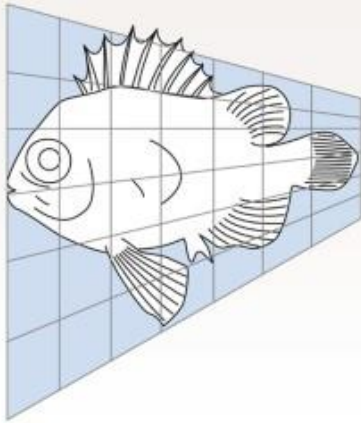
Argyropelecus olfersi



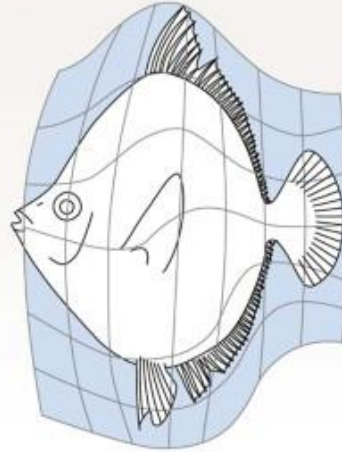
Diodon



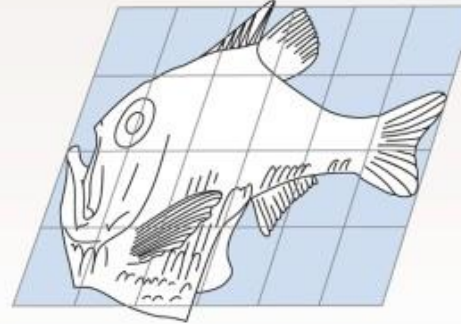
Pseudopriacanthus altus



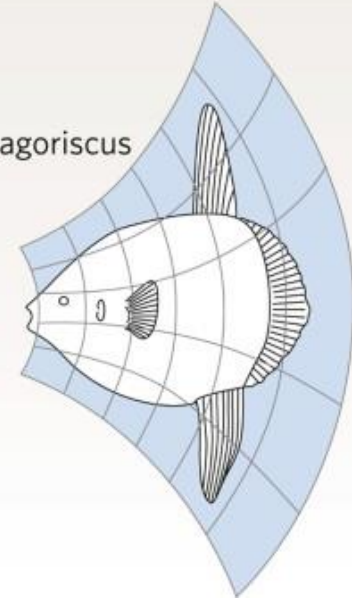
Antigonia capros



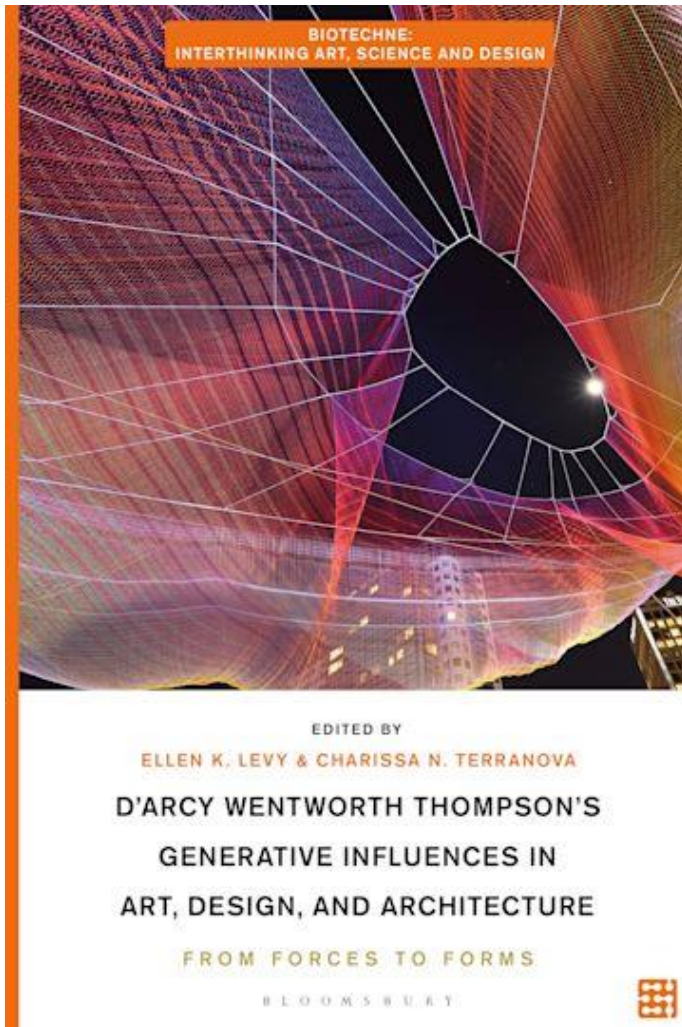
Sternoptyx diaphana



Orthogoriscus

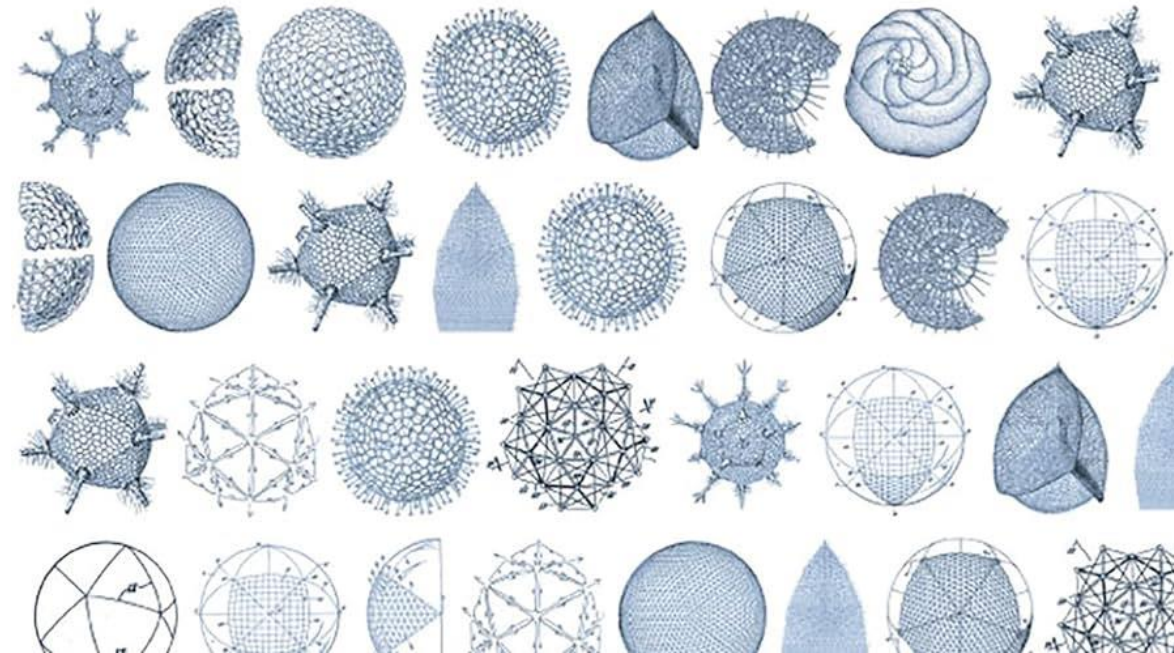


Forms shaped through evolutionary Forces



On Growth and Form Organic Architecture and Beyond

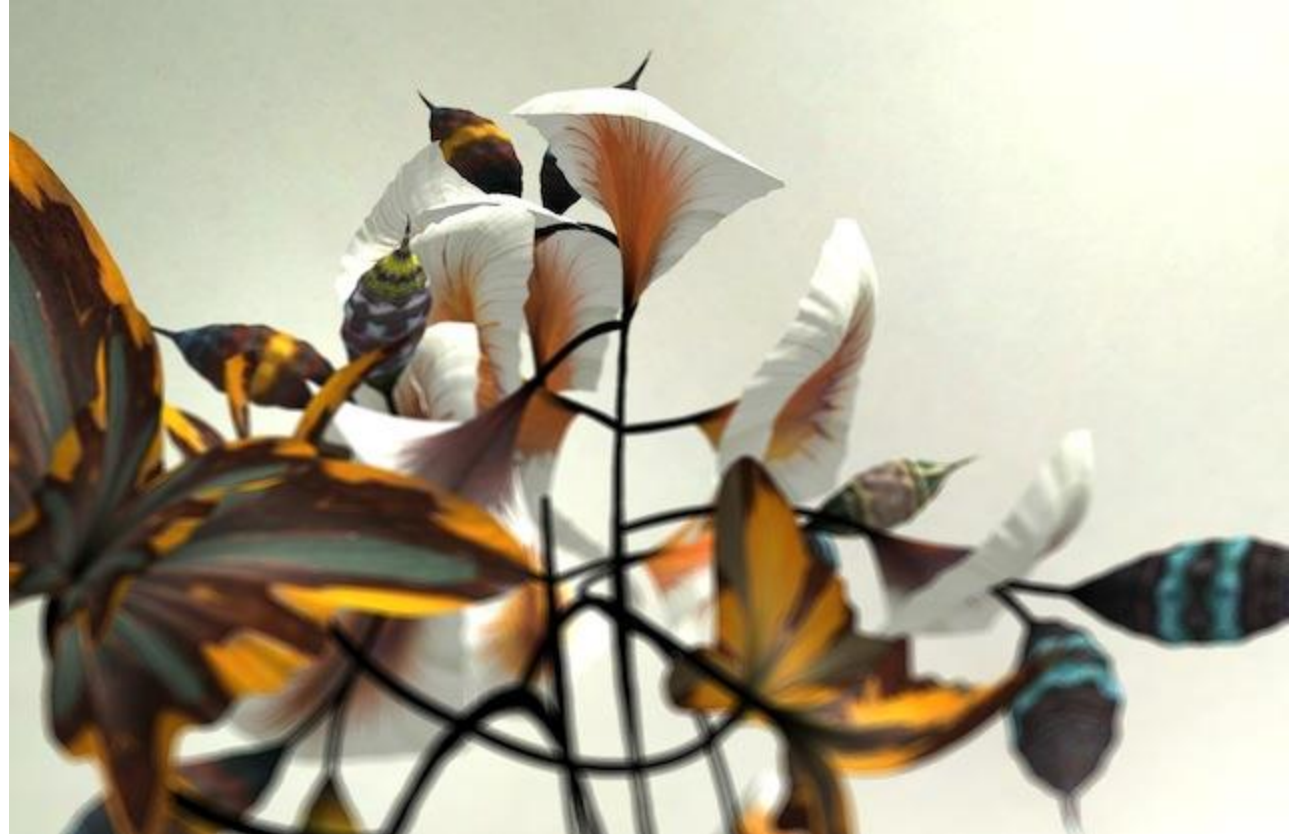
Edited by Philip Beesley & Sarah Bonnemaïson



Generative Processes and Thompson's Insights

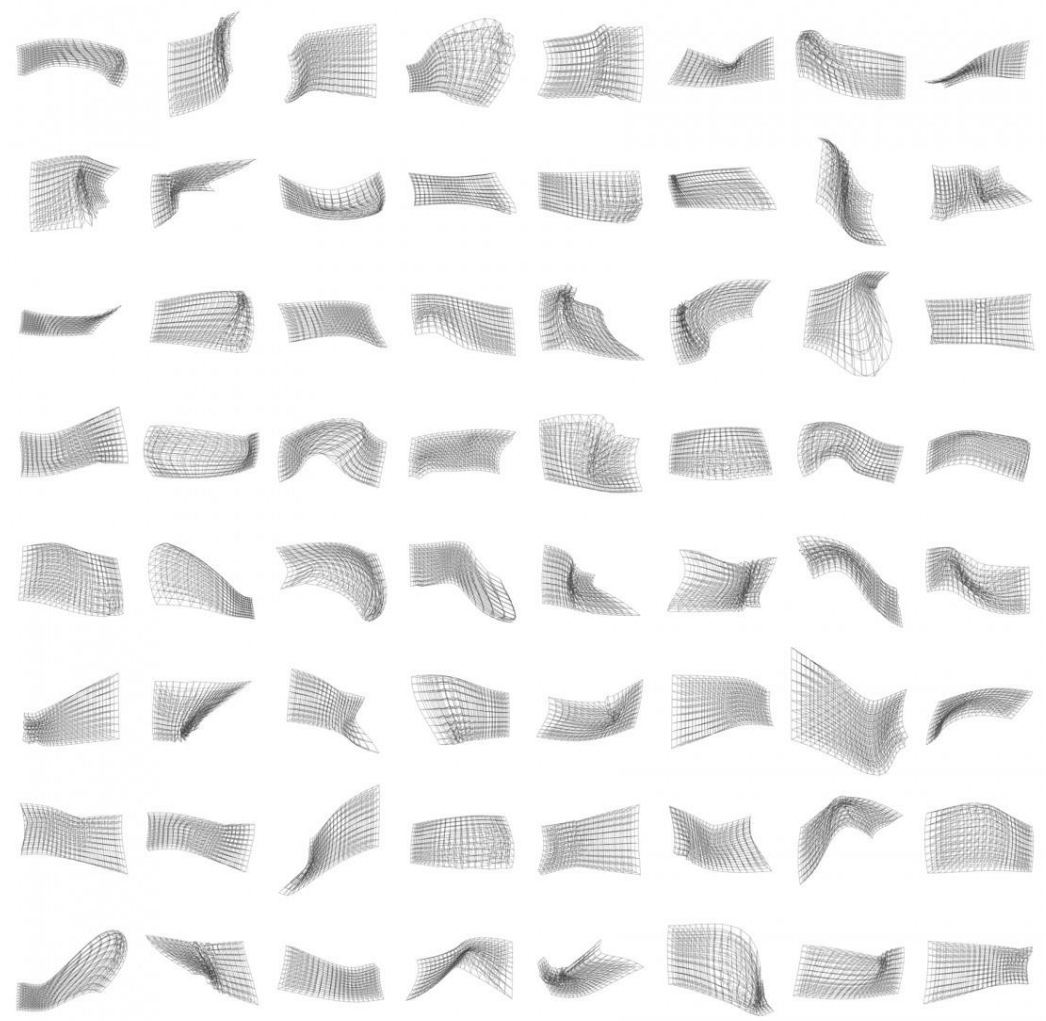
Generative Processes and Thompson's Insights

Generative Design: Applies mathematical and physical principles to generate optimised designs, reflecting Thompson's view of natural forms as products of mathematical laws.



Generative Processes and Thompson's Insights

Generative AI: Utilises algorithms to learn patterns and generate new content, paralleling the way natural processes follow mathematical rules to create complex structures.



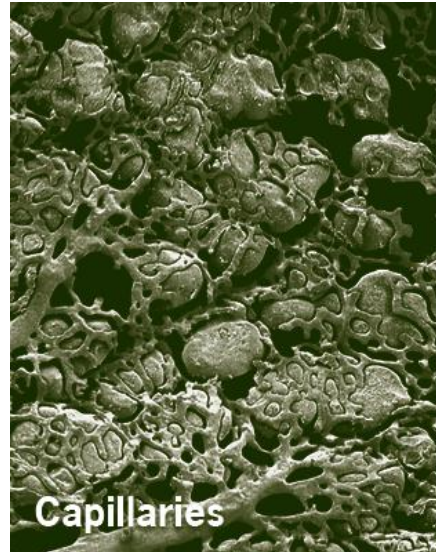
Order within **Chaos**

Complexity and
Emergence

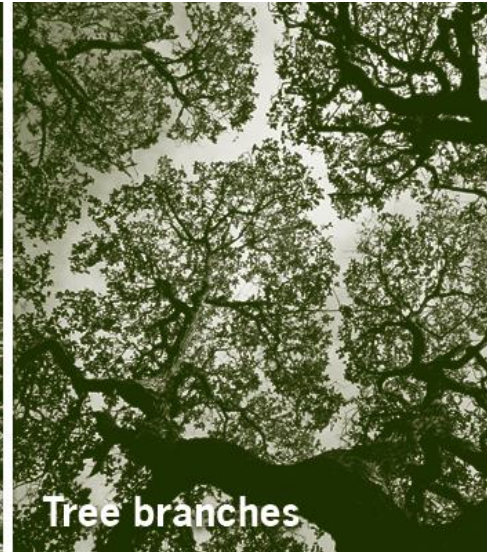


Order within Chaos

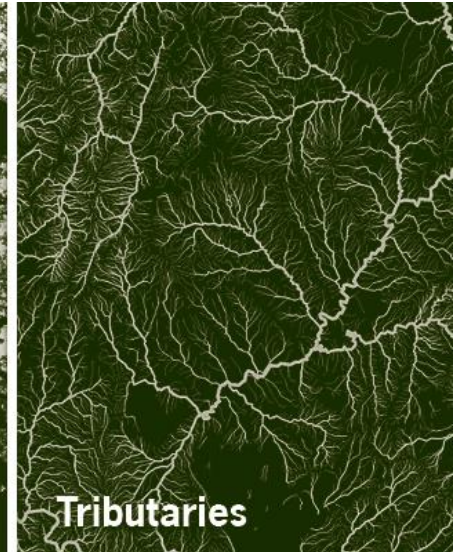
complexity
(systems, patterns, structure)



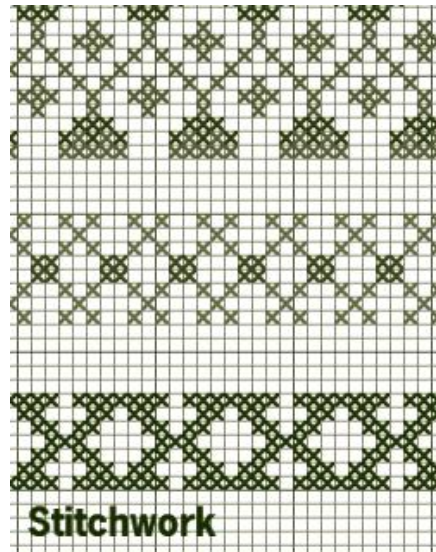
Capillaries



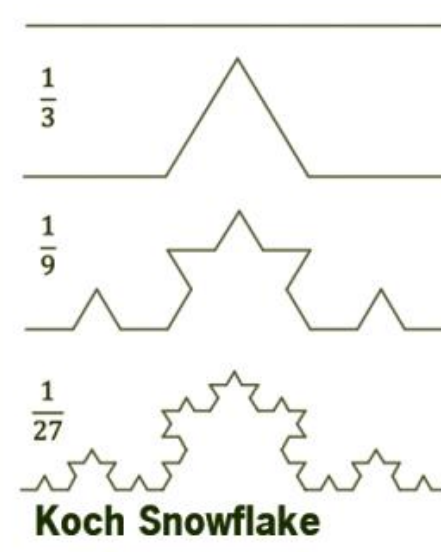
Tree branches



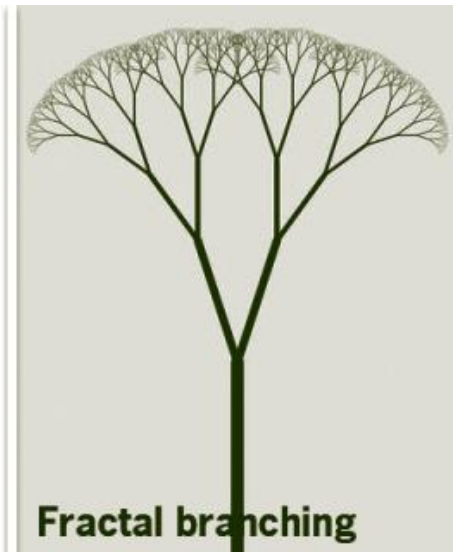
Tributaries



Stitchwork



Koch Snowflake



Fractal branching

Morphogenesis

the generation of form Morphogenesis (from the Greek morphê shape and genesis creation, literally "the generation of form") is the biological process that causes a cell, tissue or organism to develop its shape.



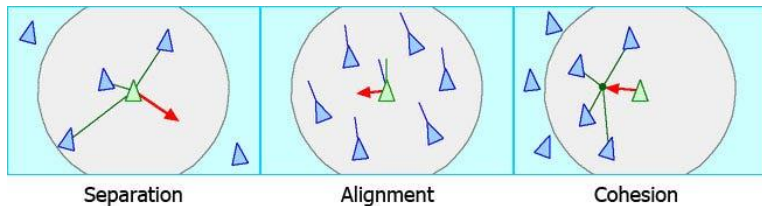
Order within Chaos

Emergence

Emergence describes the distinct patterns and behaviors that can arise out of complex systems.

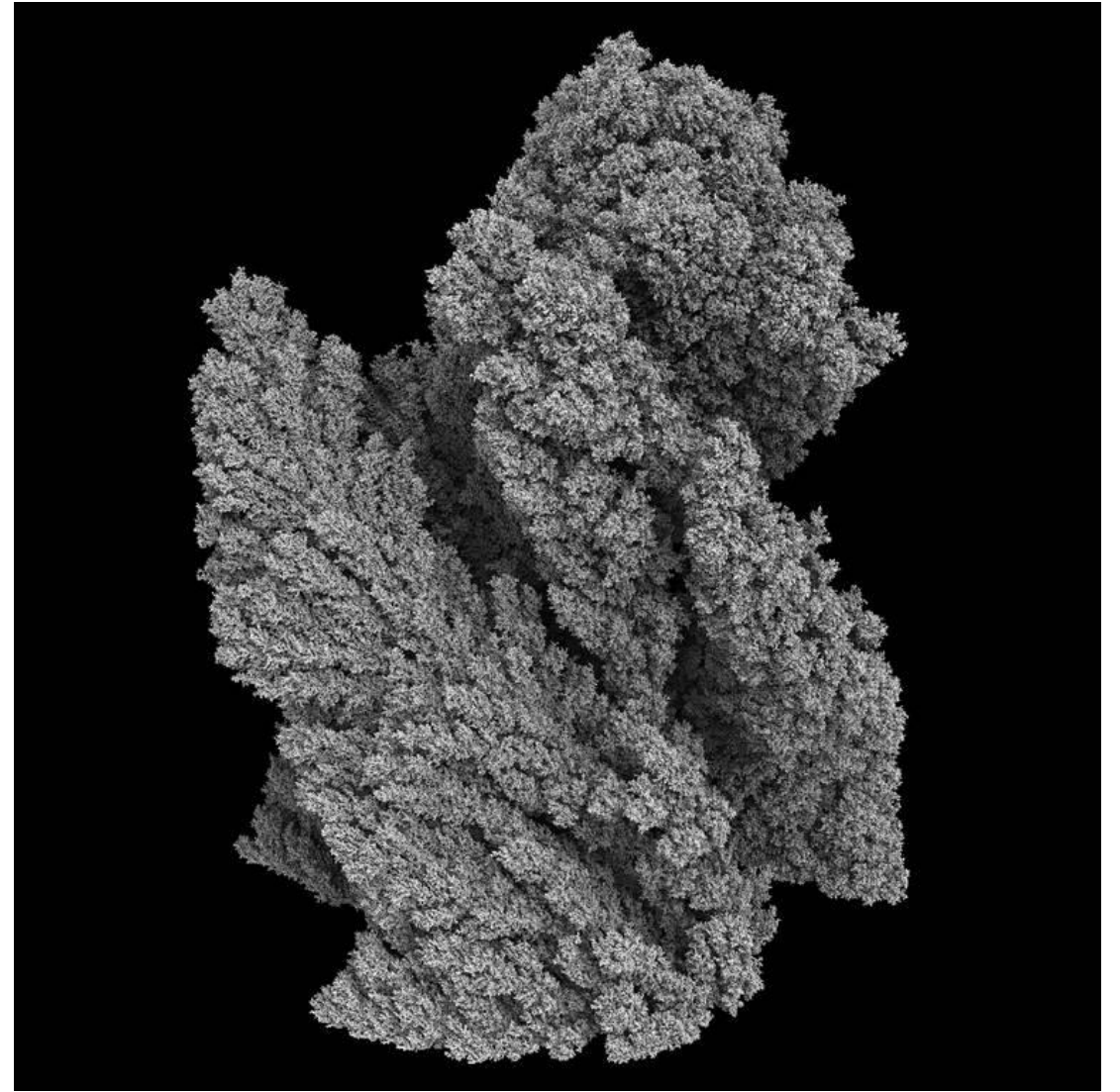
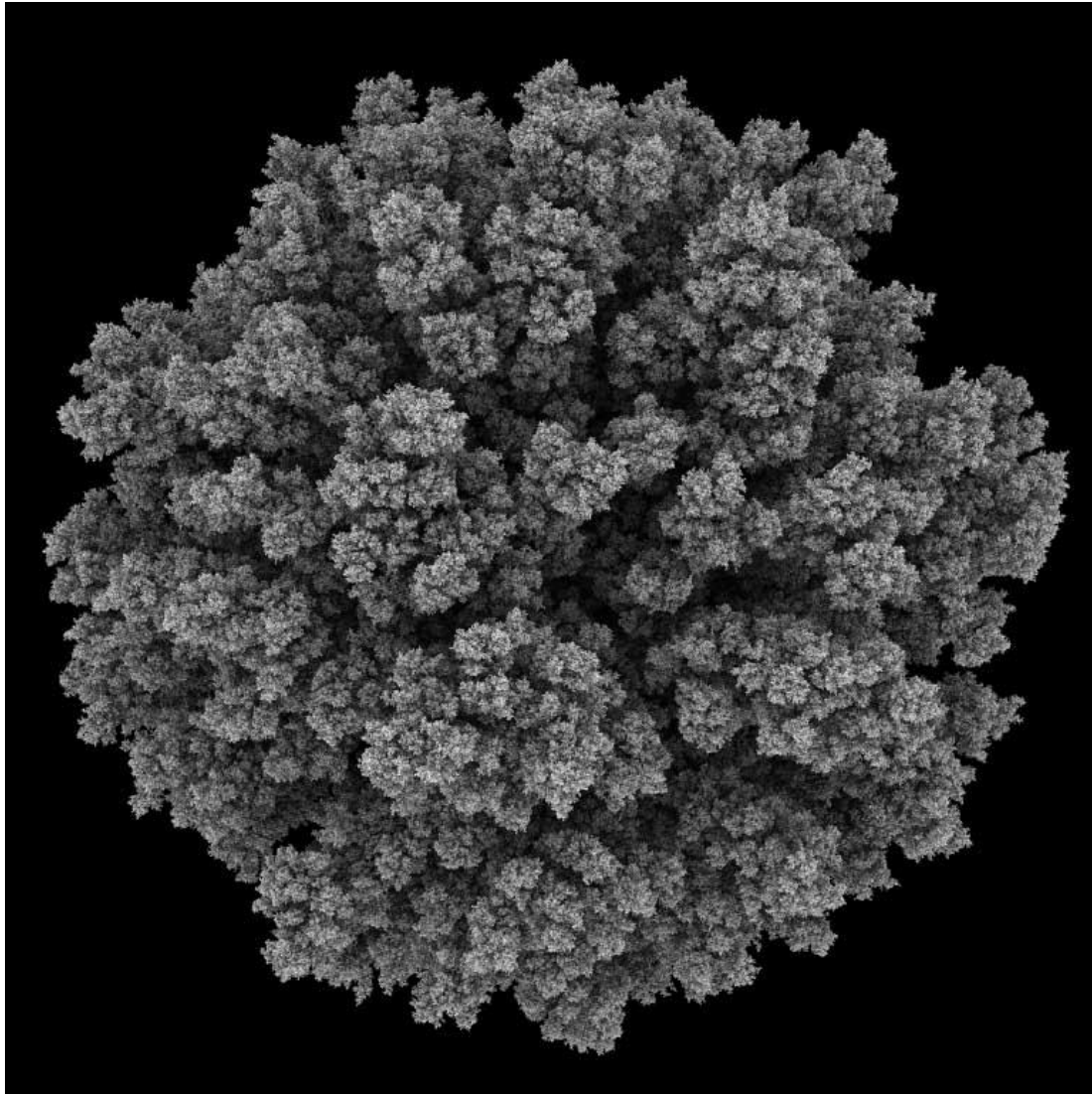
Unlocking Nature's '**hidden**' rules of behaviour

e.g. flocking systems



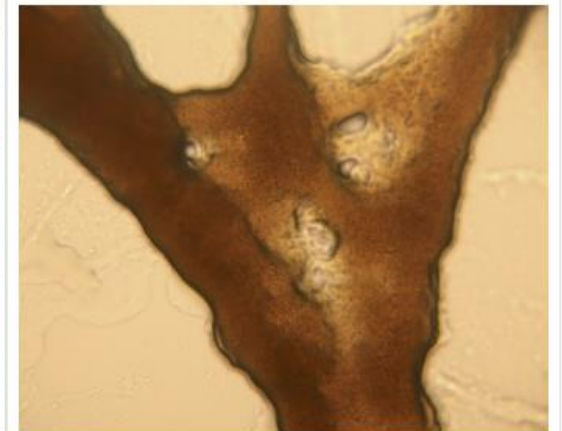
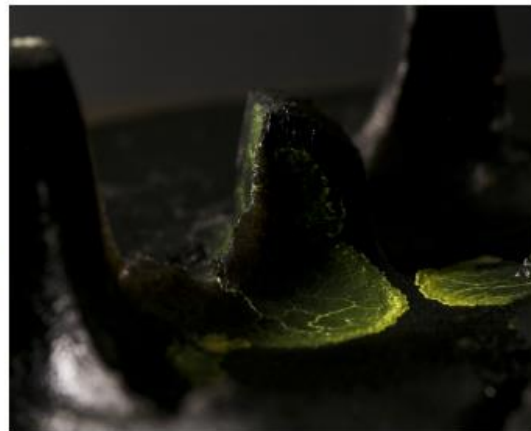
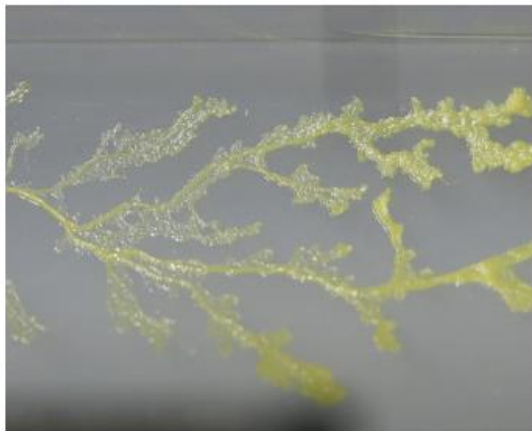
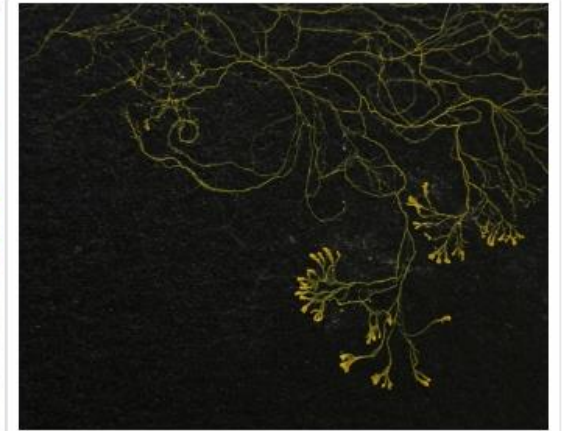
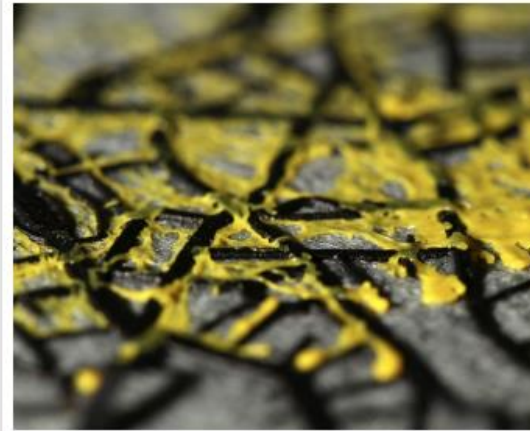
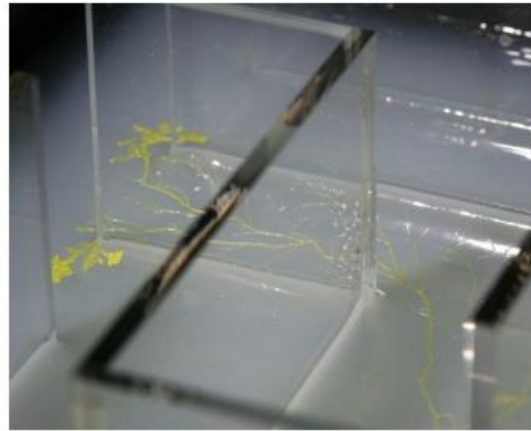
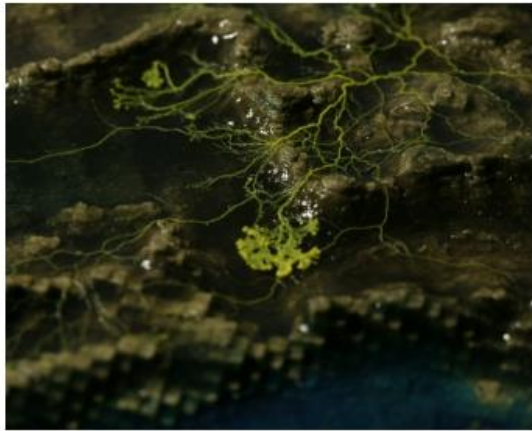






Aggregation (2007) | Andy Lomas

The Physarum Experiments| Heather Barnett



Creeping Garden

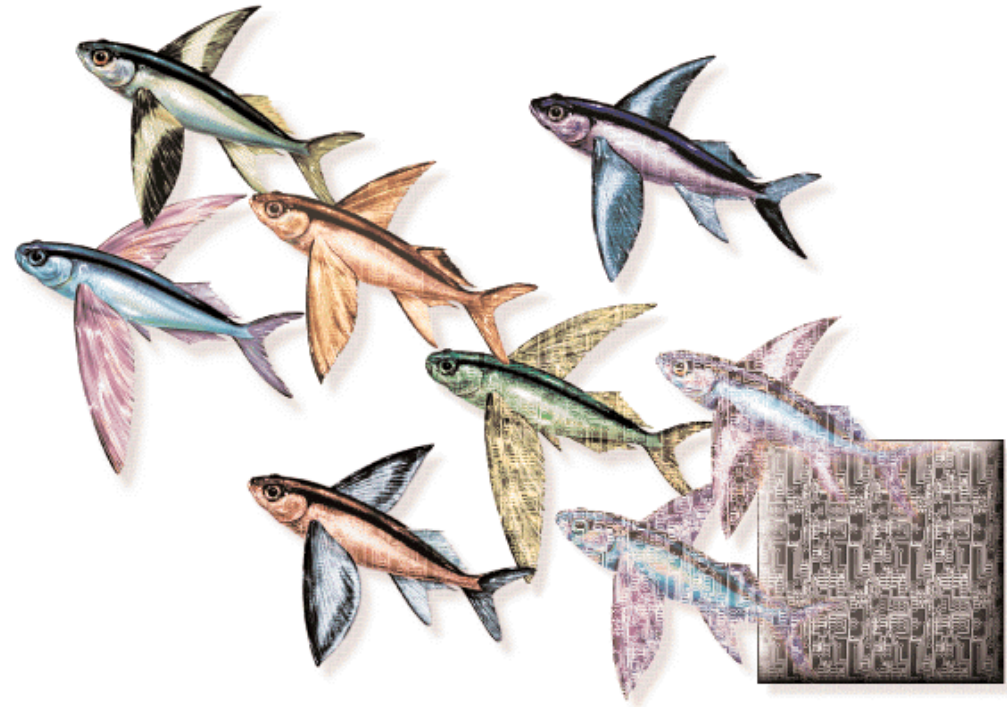
Gary William Flake

The Computational Beauty of Nature

Computer Explorations
of Fractals, Chaos, Complex
Systems, and Adaptation

Algorithms & Aesthetics

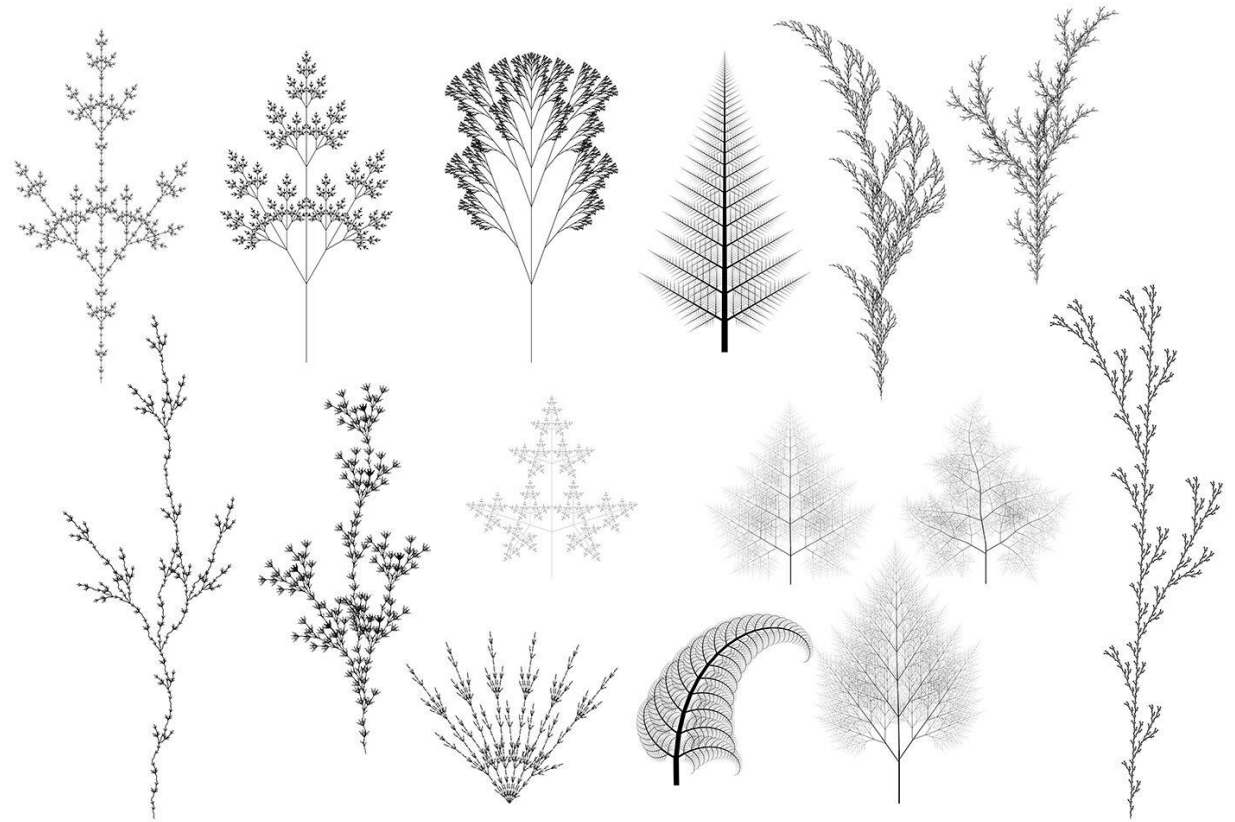
Algorithmic Generation and Natural Form



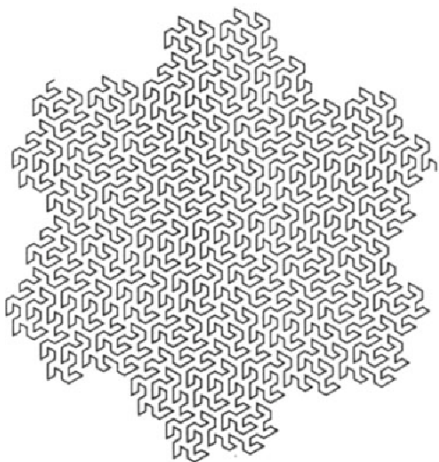
THE VIRTUAL LABORATORY

THE ALGORITHMIC BEAUTY OF PLANTS

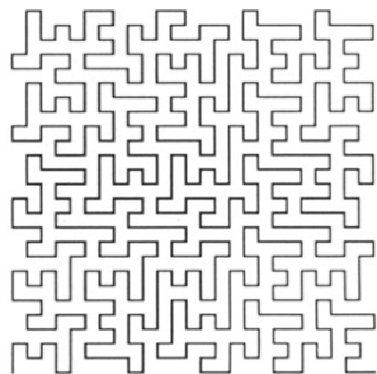
PRZEMYSŁAW PRUSINKIEWICZ • ARISTID LINDENMAYER



L-Systems | Algorithmic Beauty of Plants

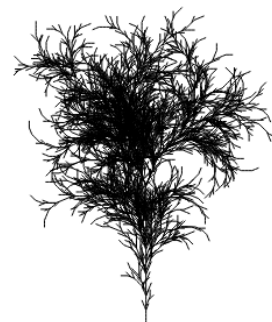
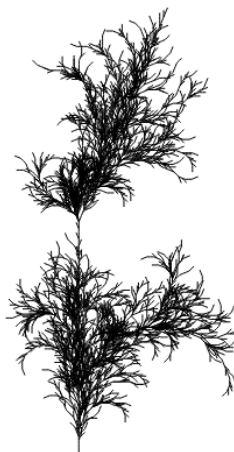
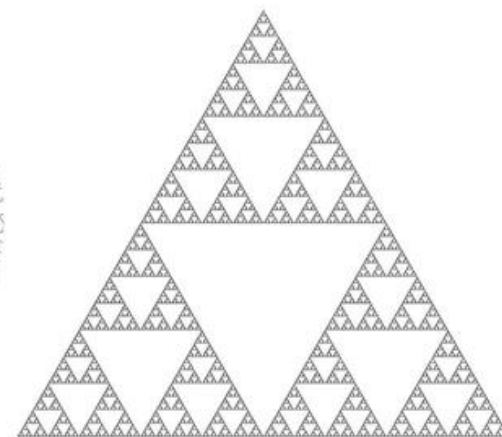
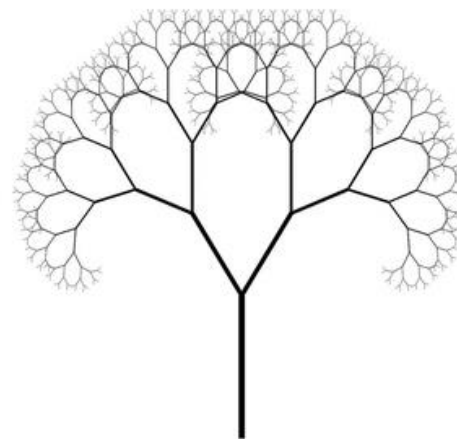


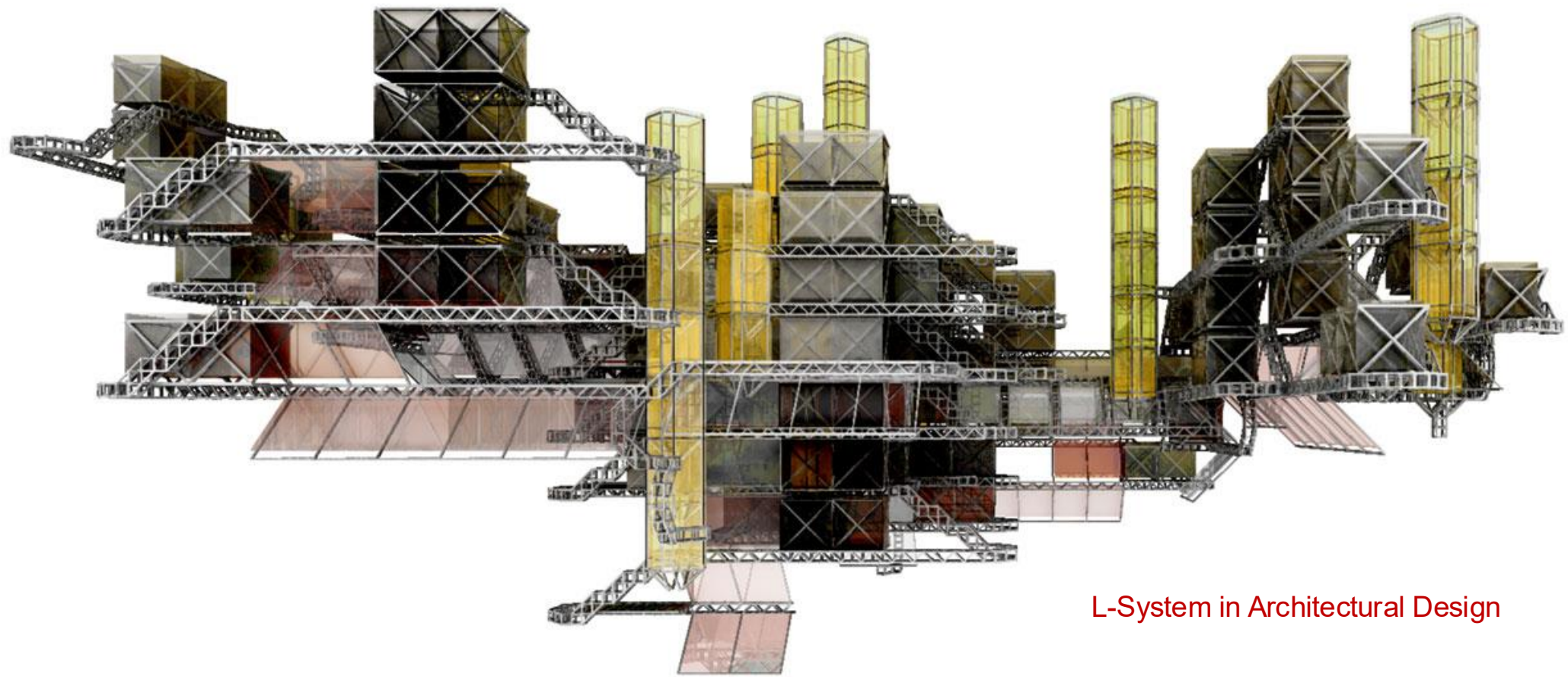
a
 $n=4, \delta=60^\circ$
 F_1
 $F_1 \rightarrow F_1 + F_r + + F_r - F_1 - - F_1 F_1 - F_r +$
 $F_r \rightarrow -F_1 + F_r F_r + + F_r + F_1 - - F_1 - F_r$



b
 $n=2, \delta=90^\circ$
 $-F_r$
 $F_1 \rightarrow F_1 F_1 - F_r - F_r + F_1 + F_1 - F_r - F_r F_1 +$
 $F_r + F_1 F_1 F_r - F_1 + F_r + F_1 F_1 +$
 $F_r - F_1 F_r - F_r - F_1 + F_1 + F_r F_r -$
 $F_r \rightarrow + F_1 F_1 - F_r - F_r + F_1 + F_1 F_r + F_1 -$
 $F_r F_r - F_1 - F_r + F_1 F_r F_r - F_1 -$
 $F_r F_1 + F_1 + F_r - F_r - F_1 + F_1 + F_r F_r$

$$f(x,y) = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix}$$

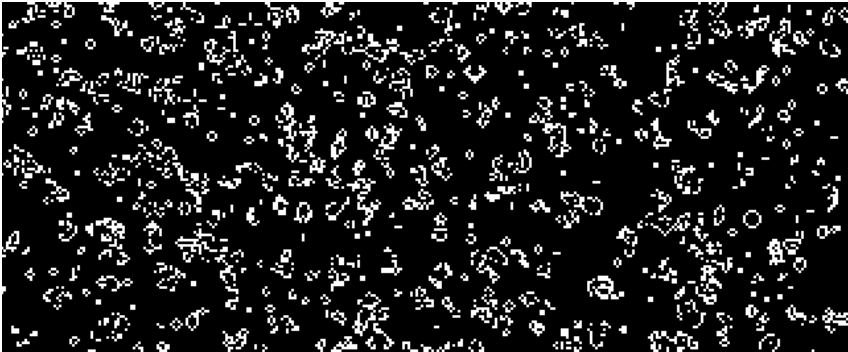




L-System in Architectural Design

Biological Cells and Cellular Automata

**difference and repetition
in the evolutionary
process of creation**

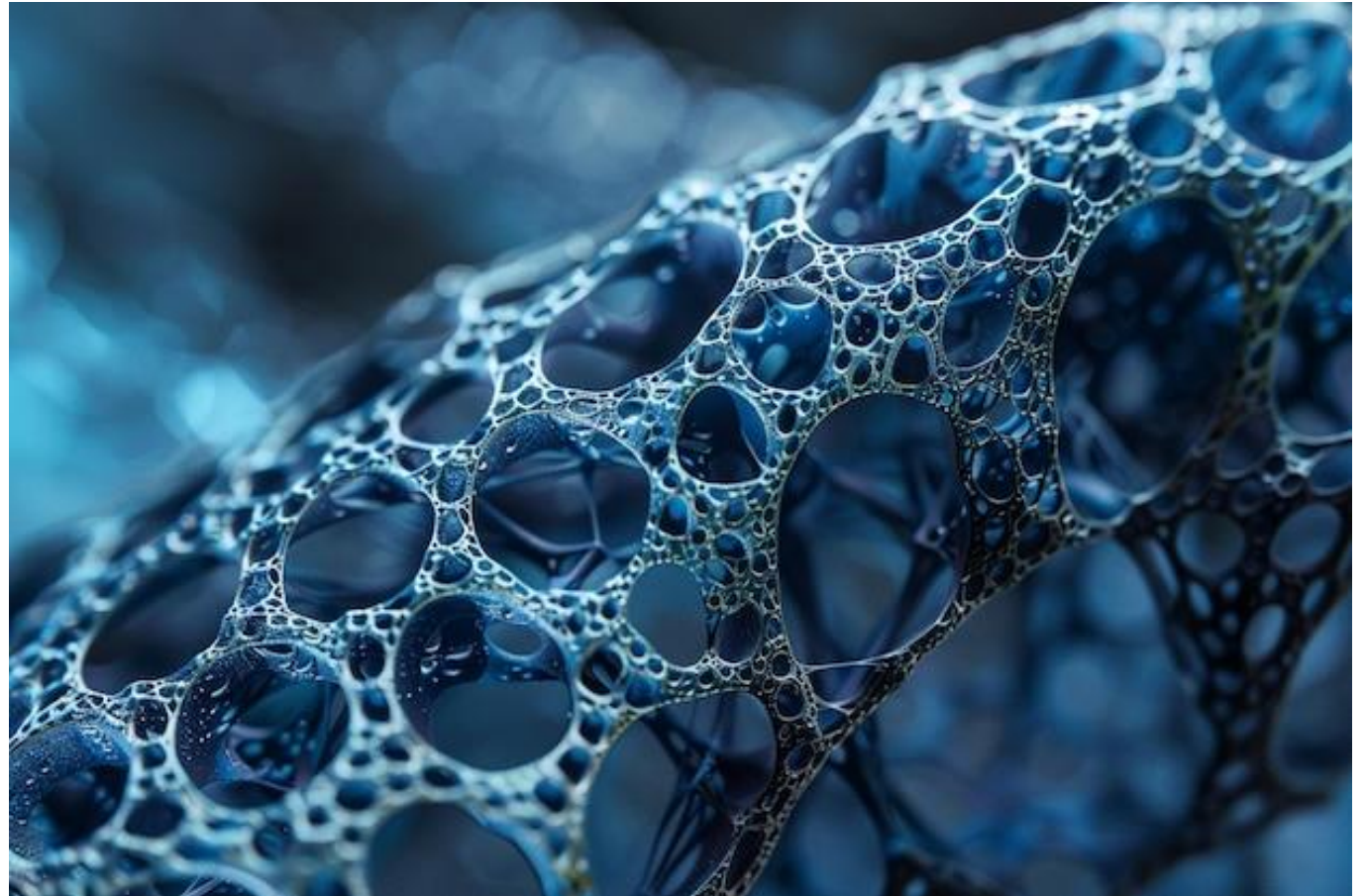


Cellular automata are grid-based models where each cell changes state based on simple rules, similar to how biological cells interact and evolve.



Harnessing Nature's Genius

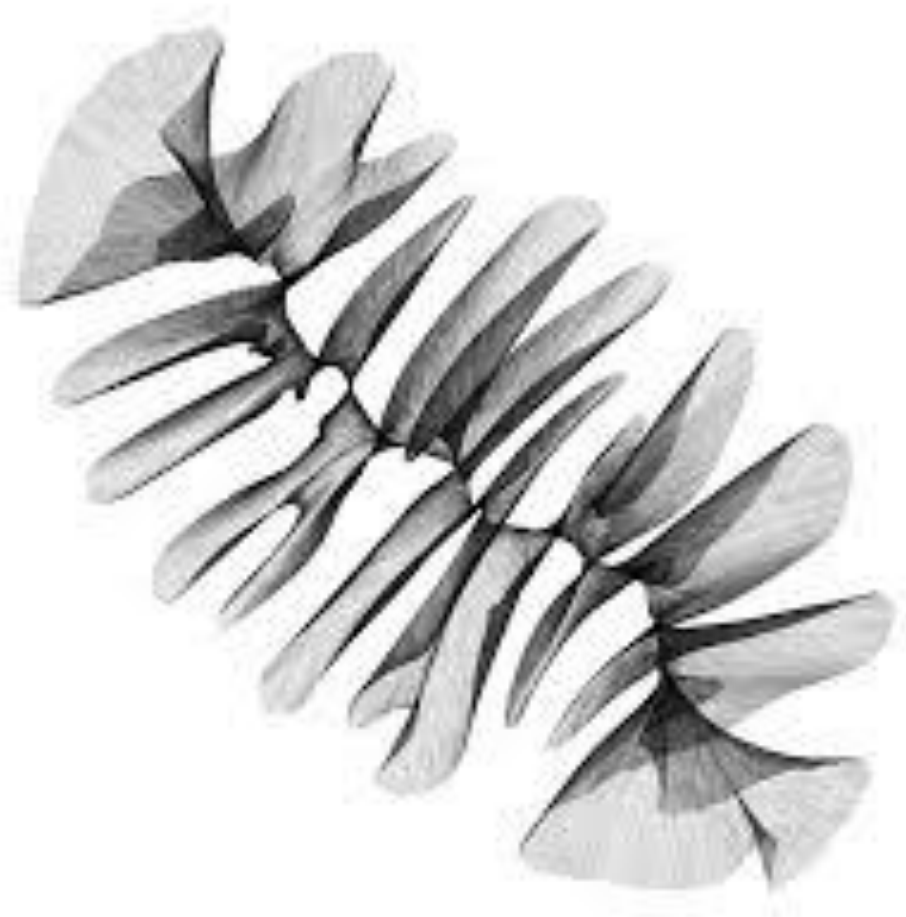
The Convergence of
Evolutionary Algorithms
and **Cellular Automata**
in Generative Design
using **AI**



Algorithms & Aesthetics

Natural Algorithms: Thompson's ideas on how natural forms arise from simple rules and constraints align with the principles of algorithmic generation in design and AI.

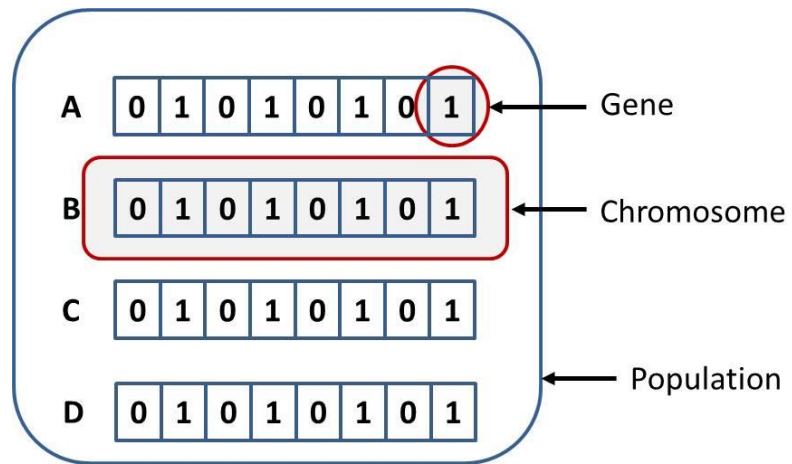
Generative Algorithms: Mimic the natural processes Thompson described, using mathematical models to create diverse and innovative designs.



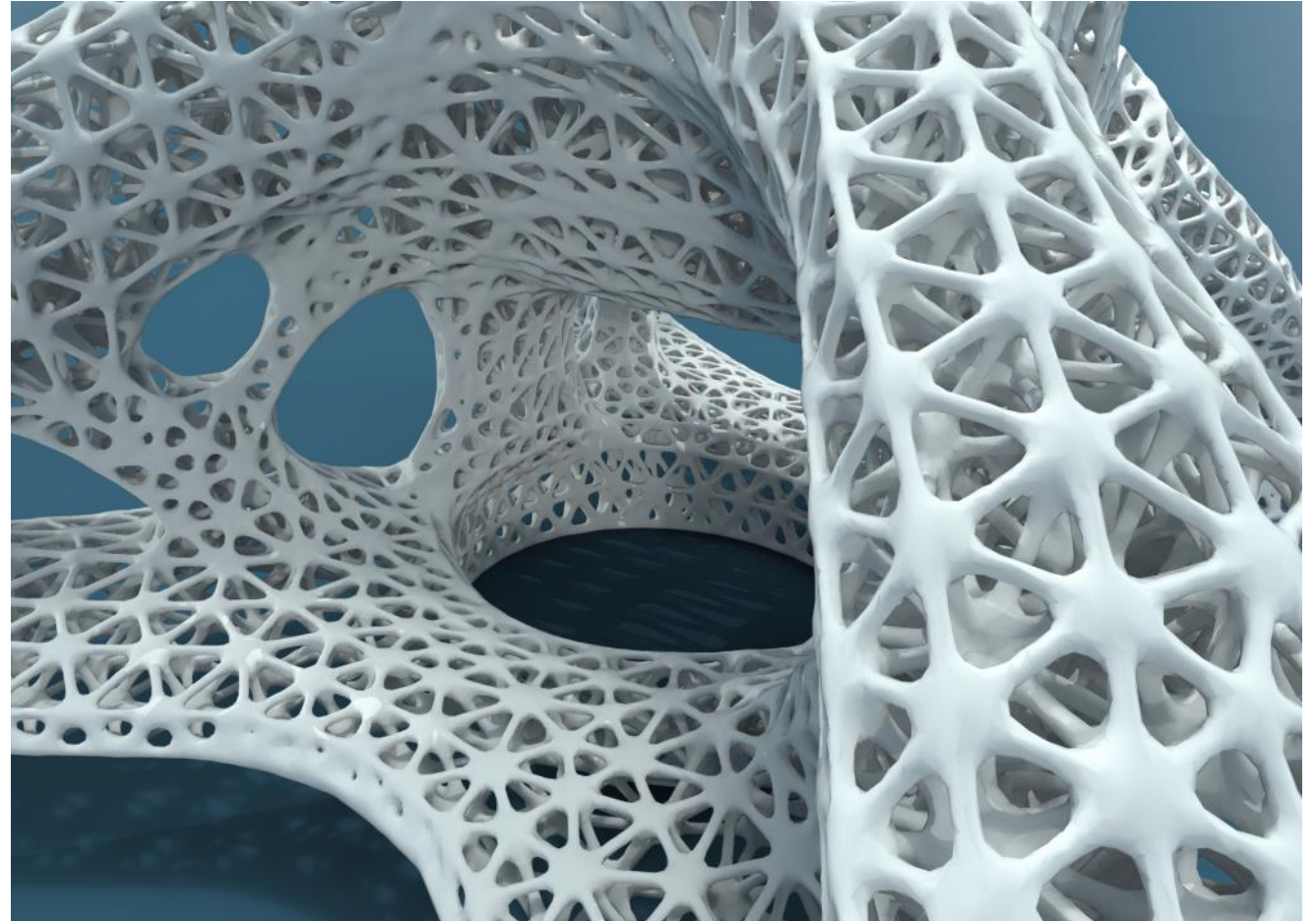
genetic algorithms

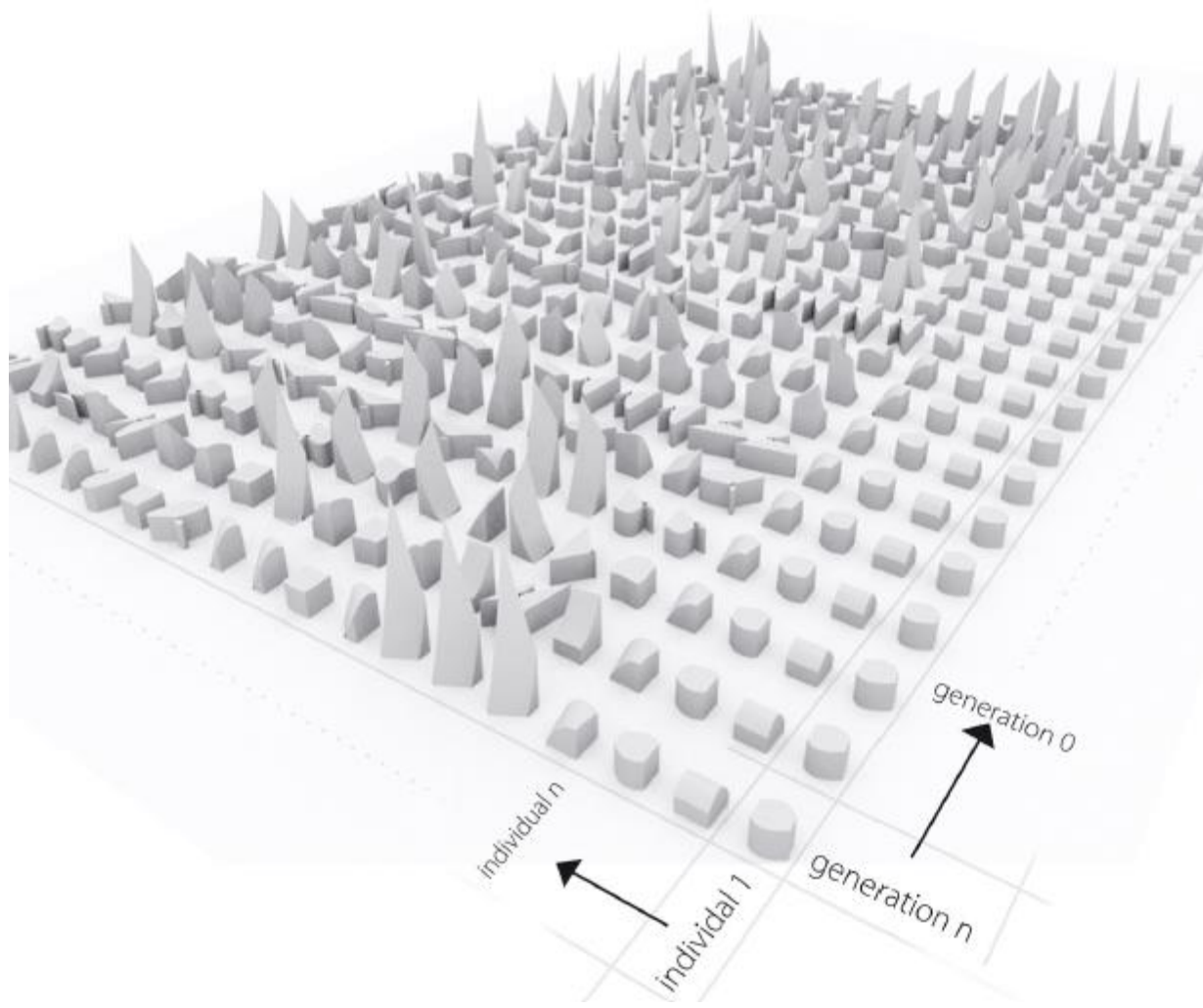
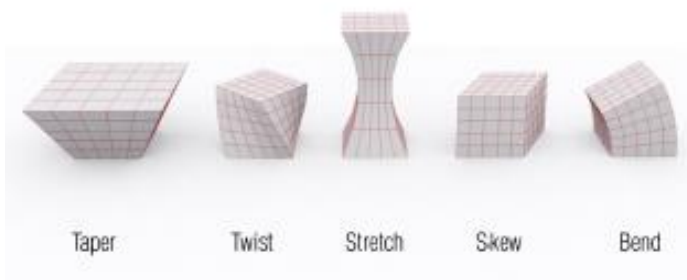
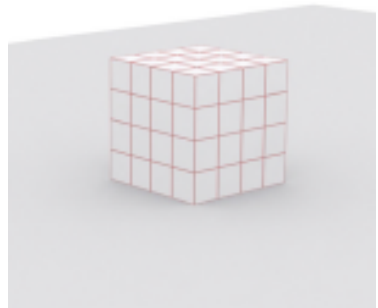
Use in Creative Design Processes

a genetic algorithm is a metaheuristic inspired by the process of **natural selection** that belongs to the larger class of **evolutionary algorithms**.



Gene, Chromosomes and Population





neural networks

A neural network is a method in artificial intelligence that teaches computers to process data in a way that is inspired by the human brain. It is a type of machine learning process, called deep learning, that uses interconnected nodes or neurons in a layered structure that resembles the human brain.



GANs

Generative Adversarial Networks

Generative Adversarial Networks use a unique approach to generating new data by pitting two **neural networks** against each other in a competitive setting. One network attempts to create new data. The other network attempts to discern whether or not it's fake. Through repeated training, both networks become better at their jobs.



GANs

Generative Adversarial Networks

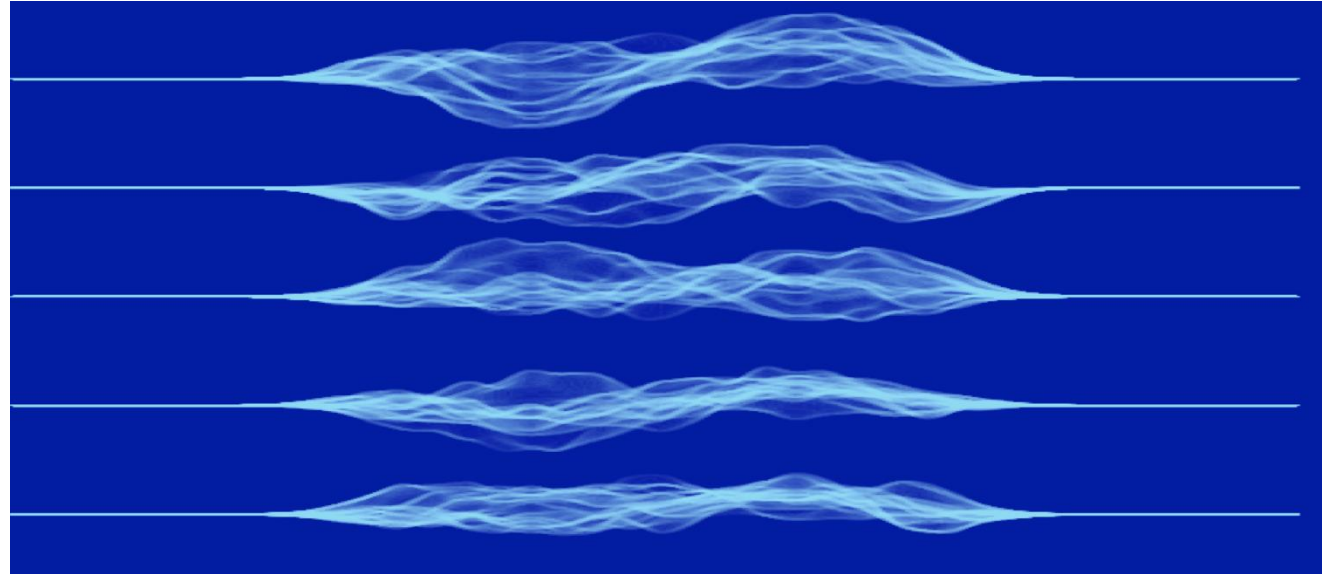
Generative Networks makes the mapping between source image and target image easier and it calculates the loss function also to improve the quality of generated target image.

Text-to-Image Generation is a task in computer vision and natural language processing where the goal is to generate an image that corresponds to a given textual description



Why?

...generative design



Generative Design is changes Traditional Processes

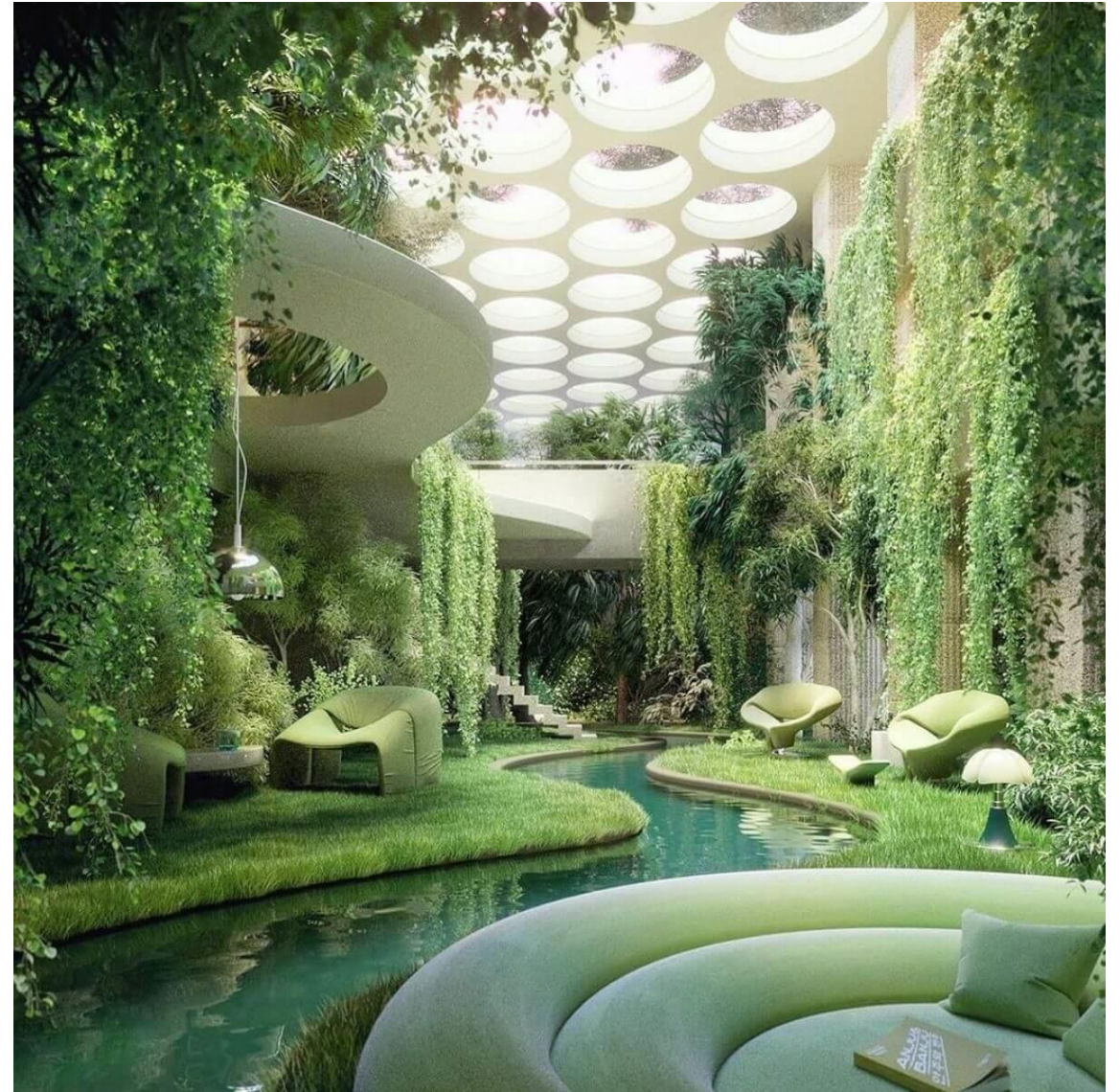
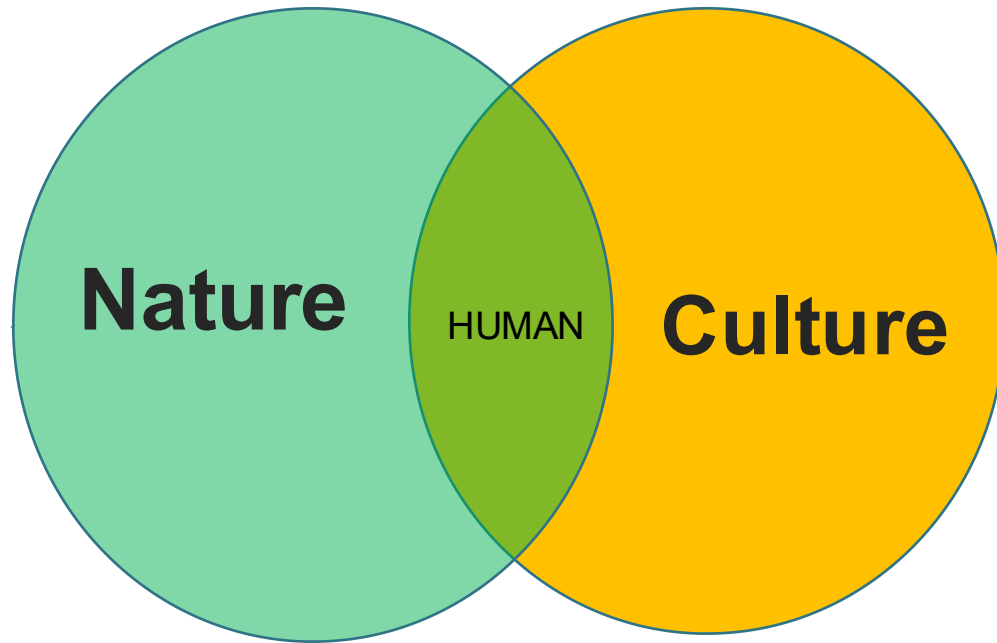
Generative design is a process of design exploration. It uses computer software to find the best possible solution for a given project

Generative design is an advanced, algorithm-driven process, sometimes enabled by AI, used to explore a wide array of design possibilities that meet predefined criteria set by engineers or designers.



Biophilic Design

Biophilic refers to the inherent human inclination to affiliate with nature and other forms of life.



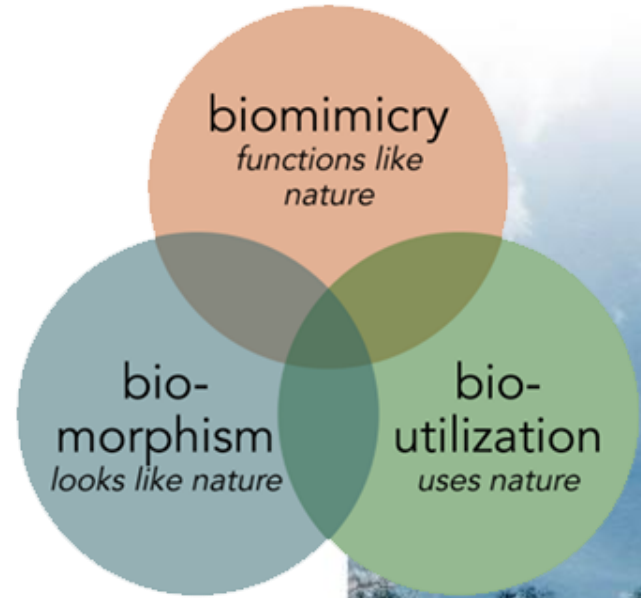
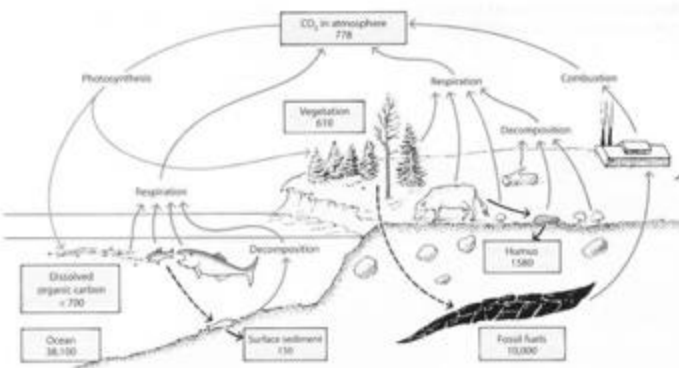
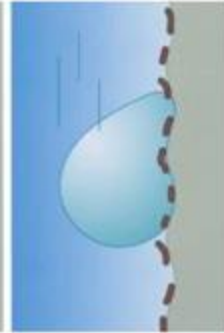
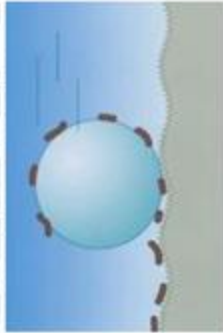
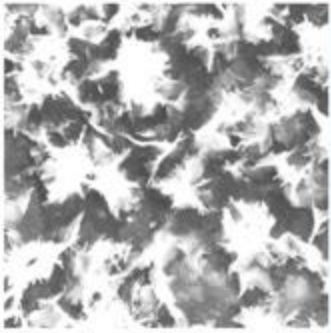
Biomorphism

Biomorphism refers to designs that visually resemble elements from life (they “look like” nature), whereas biomimetic designs focus on function (they “work like” nature).





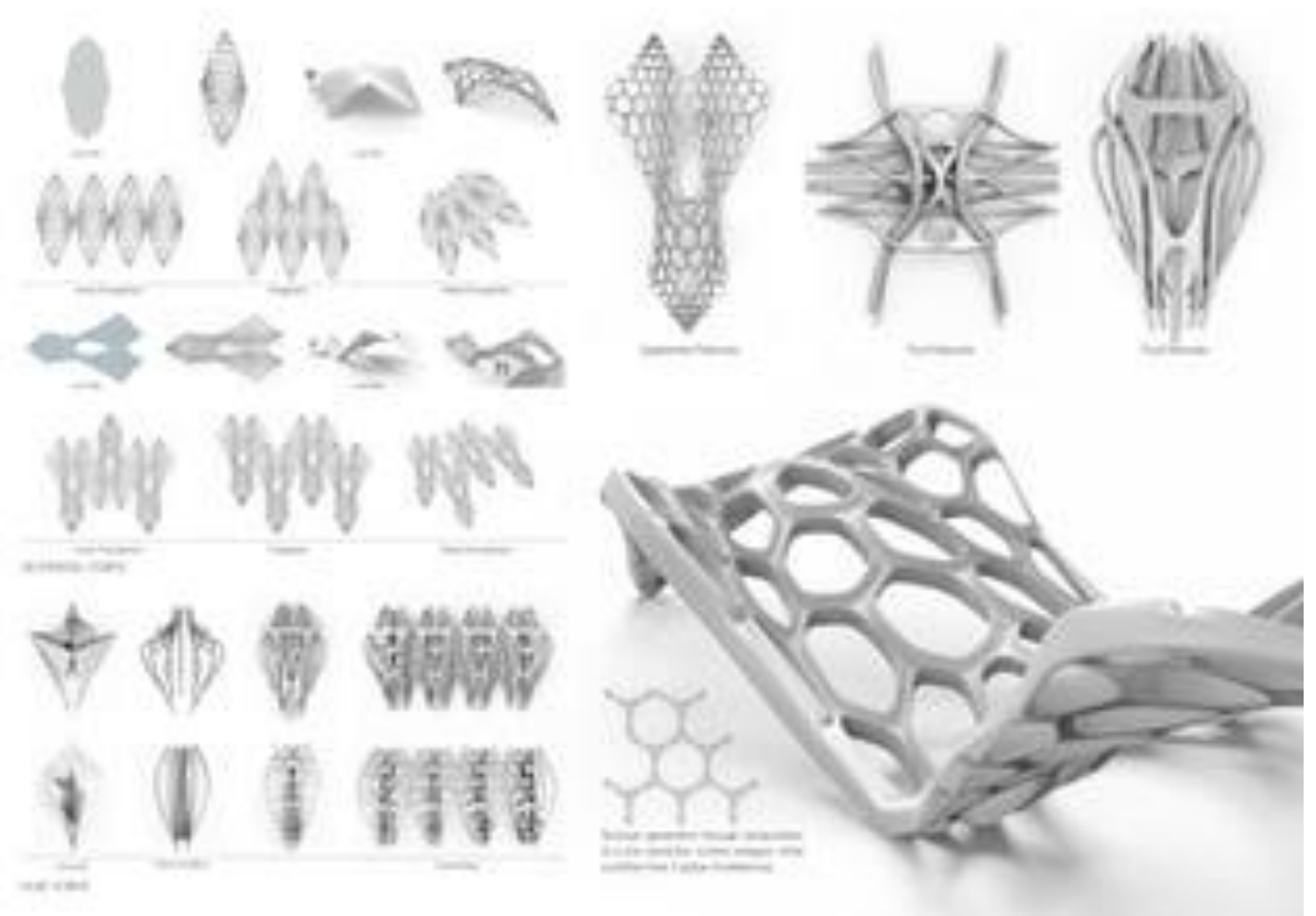
RATIO: $\frac{a}{b} = \frac{c}{d}$
 PROPORTION: $\frac{a}{b} = \frac{c}{d} = \frac{e}{f} = \frac{g}{h} = \frac{i}{j} = \frac{k}{l} = \frac{m}{n}$



TATE
+ CO

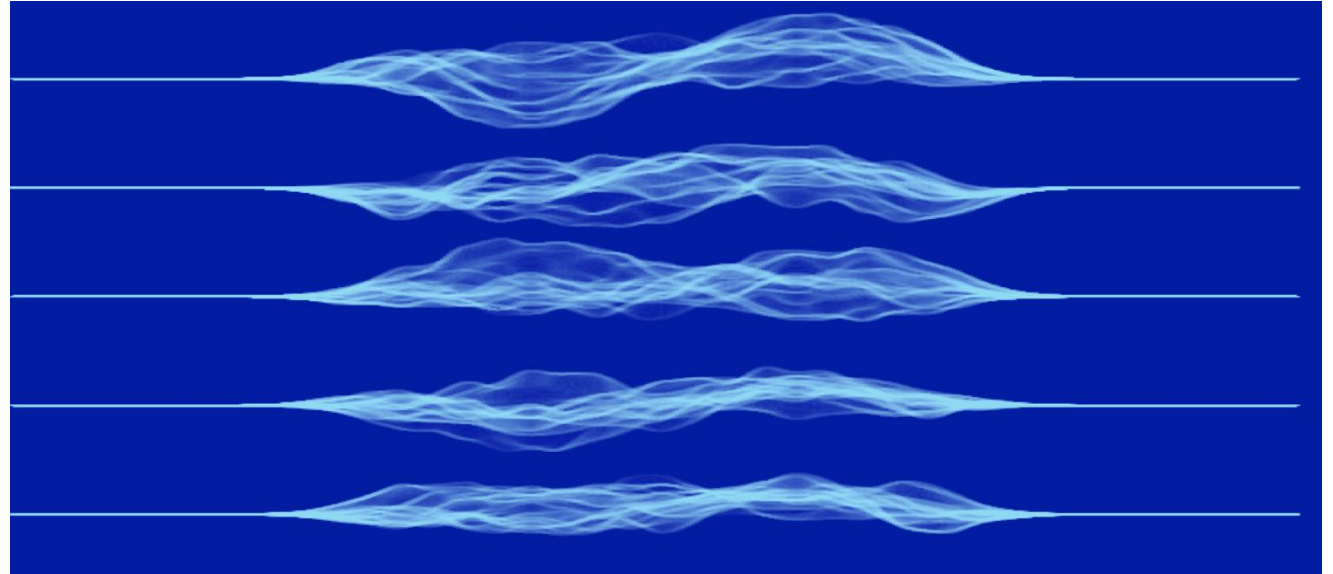
‘Digital’ Morphogenesis

Morphogenesis: The iterative process of form development in nature, guided by genetic and environmental factors, is mirrored in generative design and AI.



How?

...does generative design
work?



Repetition as a Creative Tool

the role of **repetition** in
design aesthetics

techniques for leveraging
repetition in generative design

repetition in **nature** and their application
in design



techniques for leveraging **repetition**
in generative design

rhythms and patterns



repetition in nature and their
application in design

Natural Patterns and Human Well-being
A Deep Connection



Difference as a Driver of Innovation

The importance of introducing **variation**

Methods to incorporate **difference and**

contrast in generative design

Balancing **repetition and difference** to

achieve innovative outcomes

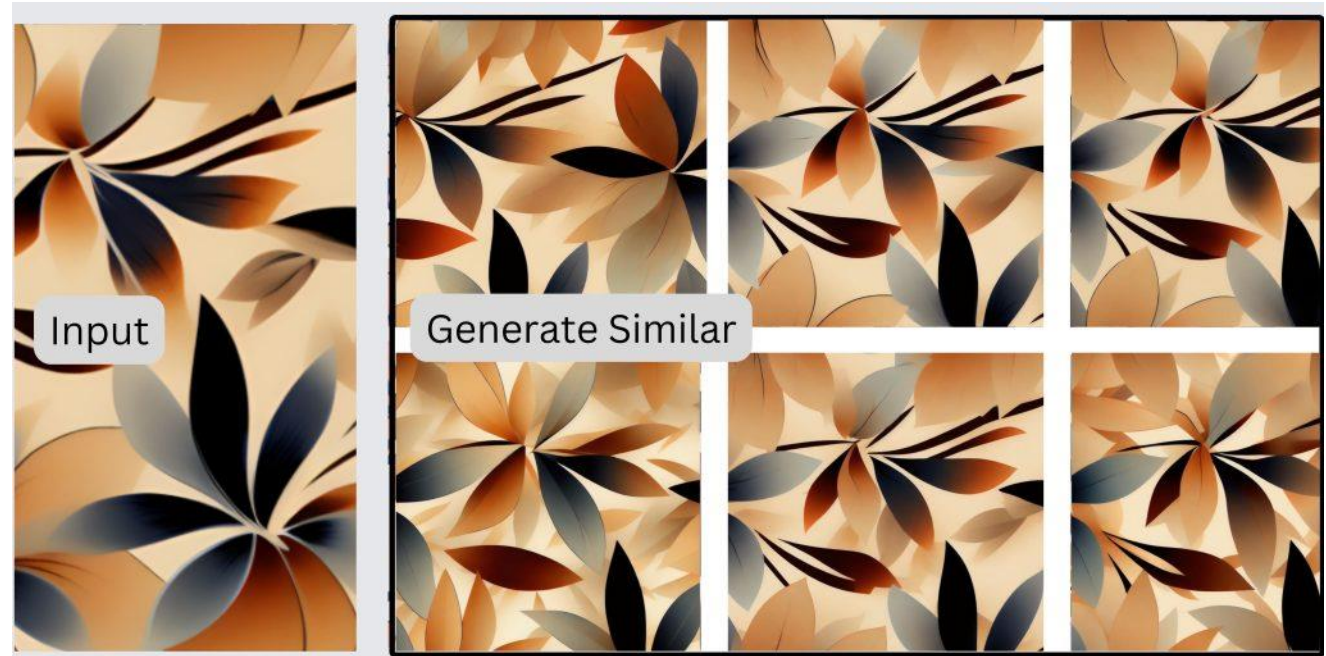
For the new – in other words, **difference** – calls forth forces in thought which are **not the forces of recognition**, today or tomorrow, but **the powers of a completely other model**, from an unrecognised and unrecognisable terra incognita.

Deleuze, *Difference and Repetition*, 1994, p.136



Difference as a Driver of Innovation

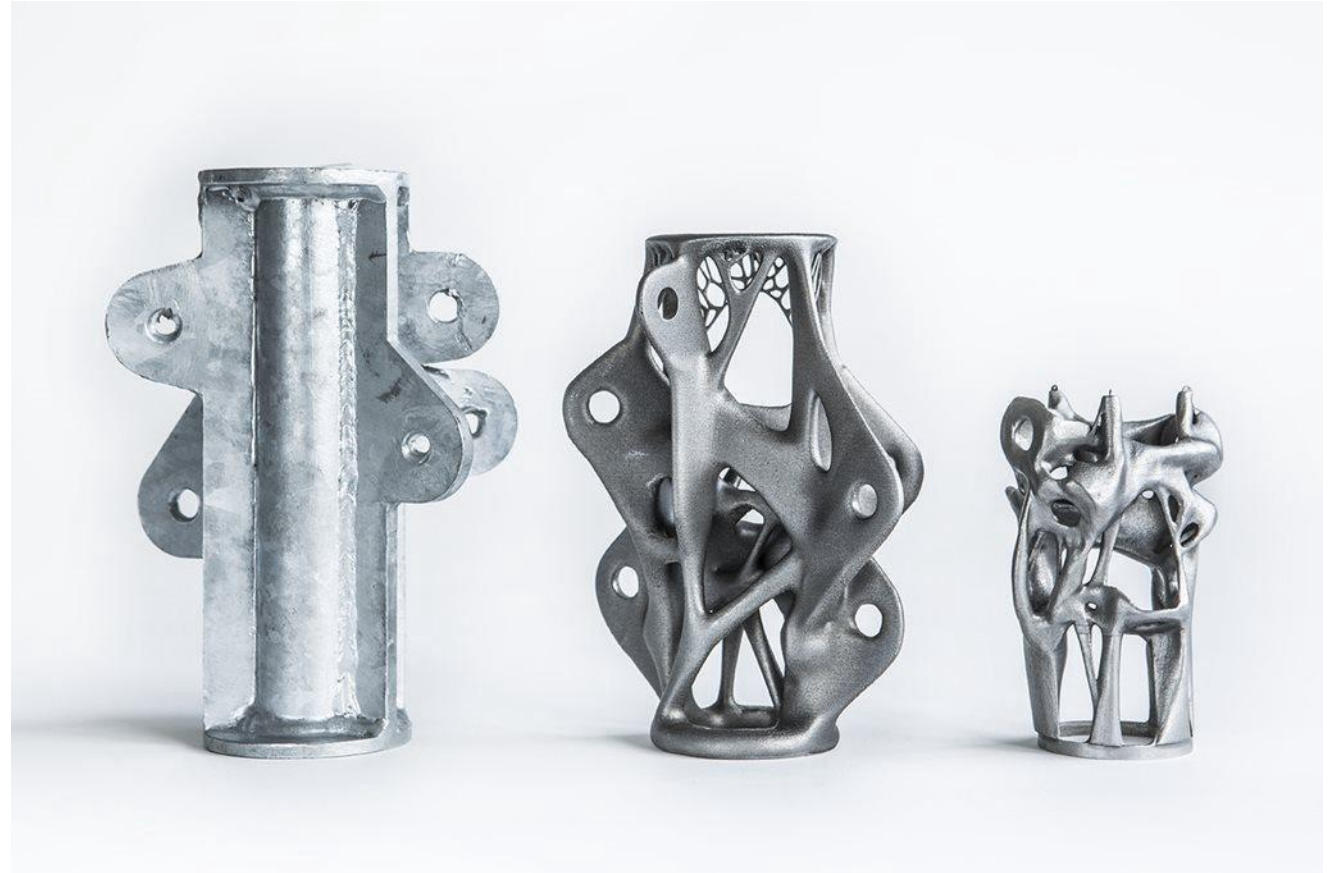
the importance of
introducing **variation**



form **and** function

methods to incorporate
difference in
generative design

balancing
repetition and **difference** to
achieve innovative outcomes



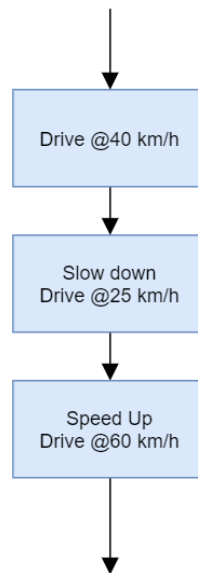
three basic programming constructs

Iterative Processes

Iterative Design: Generative processes evolve designs through continuous iteration and refinement, similar to the gradual development of natural forms.

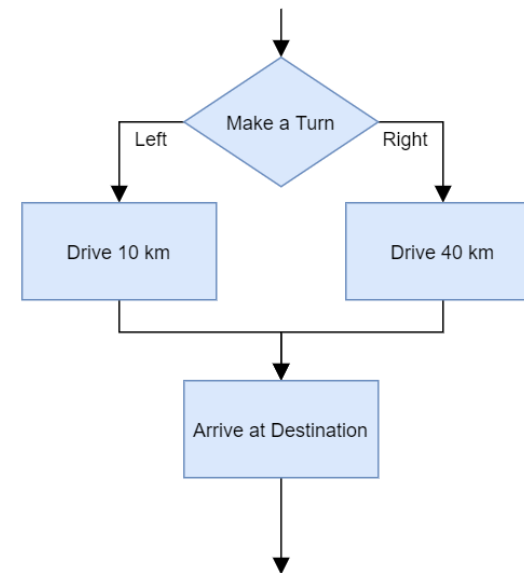
The speed of computation – computers very good at repetition and difference...

Sequence



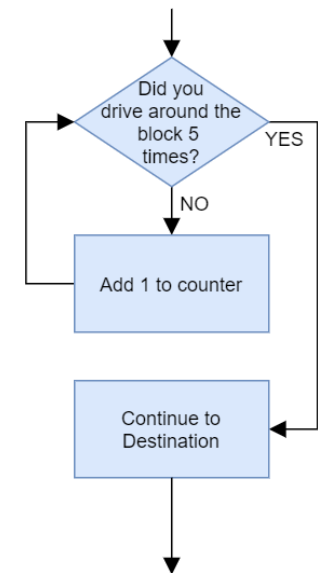
Sequence

Selection



Selection

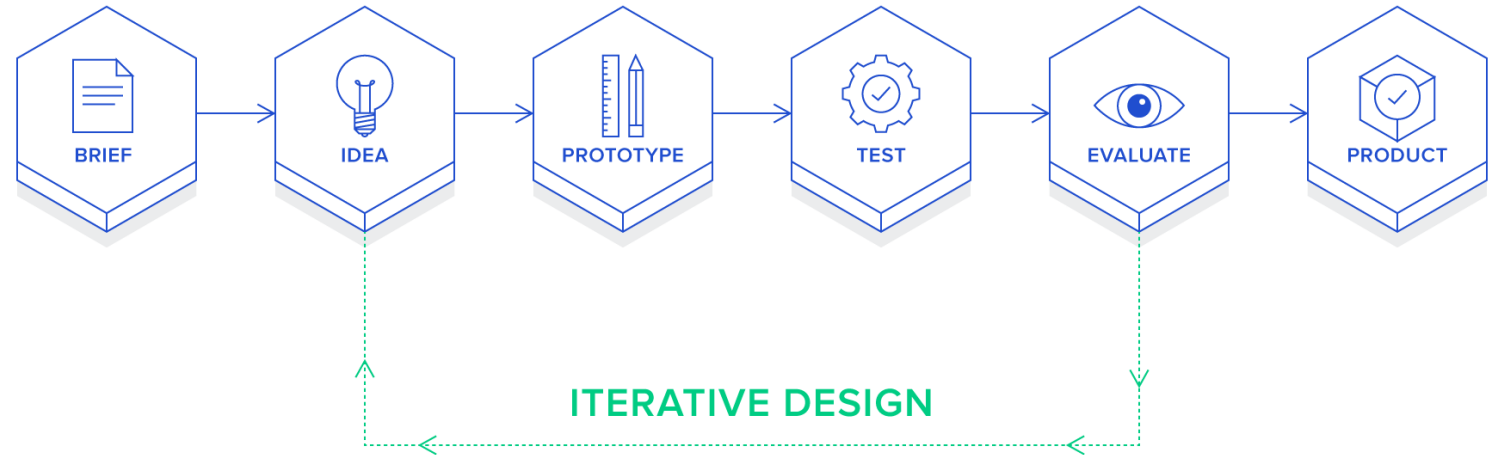
Iteration



Iteration

Iterative Processes

Constraints, Feedback Loops, and Optimization



Natural Constraints: Physical and environmental constraints shape the growth of natural forms, a concept central to D’Arcy Thompson’s work.

Design Constraints: In generative design and AI, constraints guide the creation of optimized and functional designs, analogous to natural selection processes.

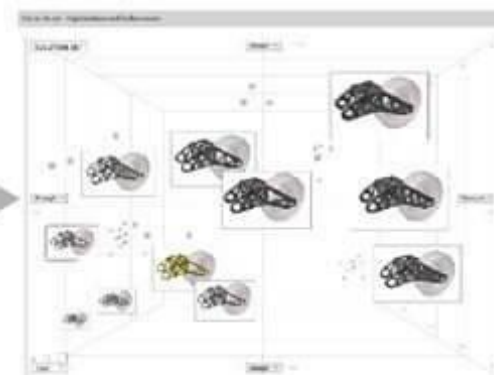
INSPIRE



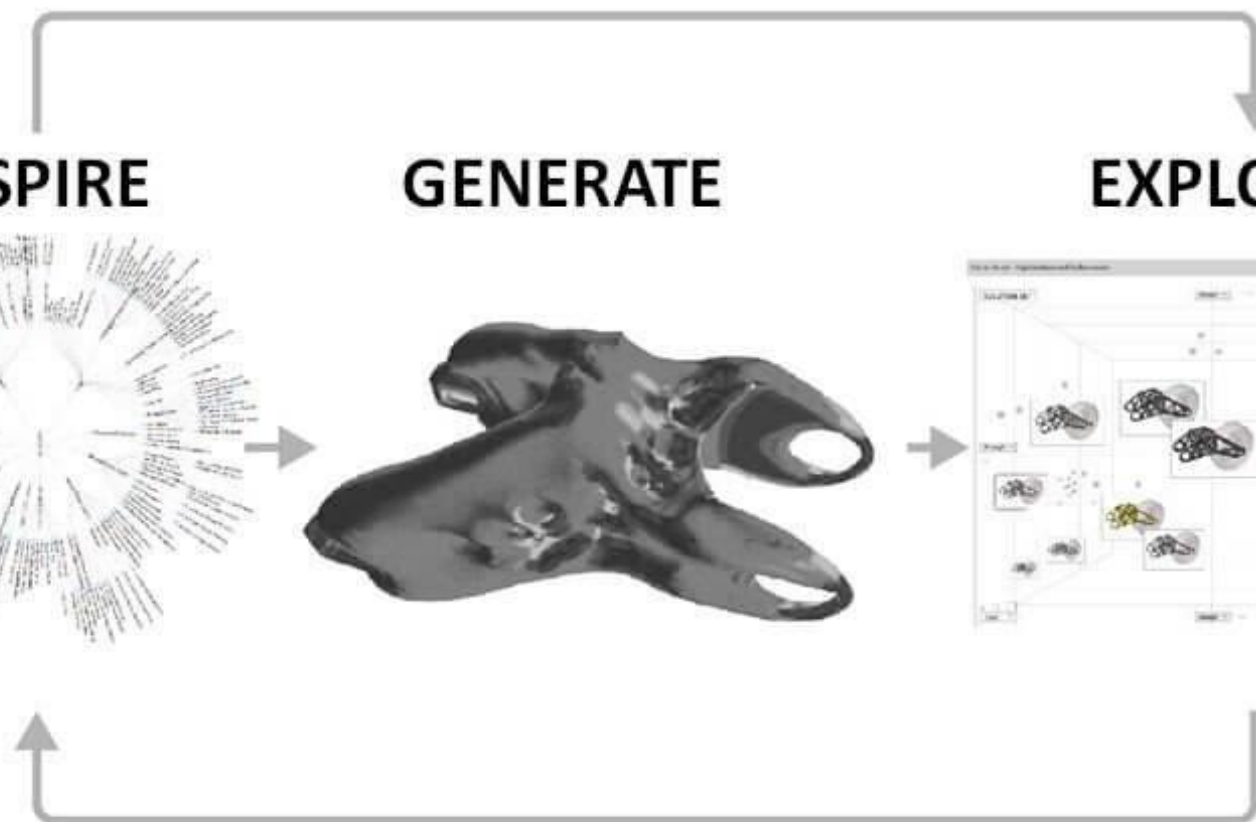
GENERATE

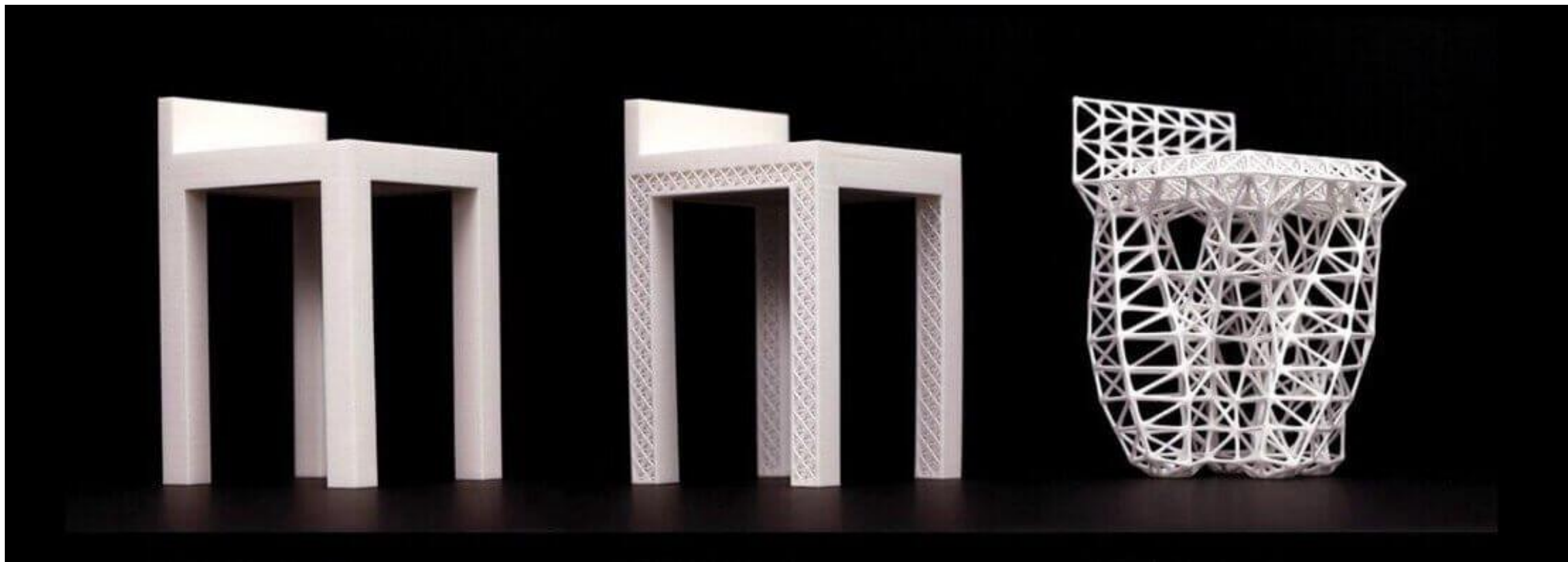


EXPLORE



FABRICATE





parametric design

Parametric design uses **parameters** to **define a set of rules or constraints**, allowing for the dynamic alteration of design elements based on these parameters. It's about defining relationships between design elements.



Procedural Generation

Creating infinite algorithmic realities

Procedural design involves using **algorithms** and predefined rules to generate complex structures and patterns. It's heavily reliant on the step-by-step execution of a series of operations or procedures.

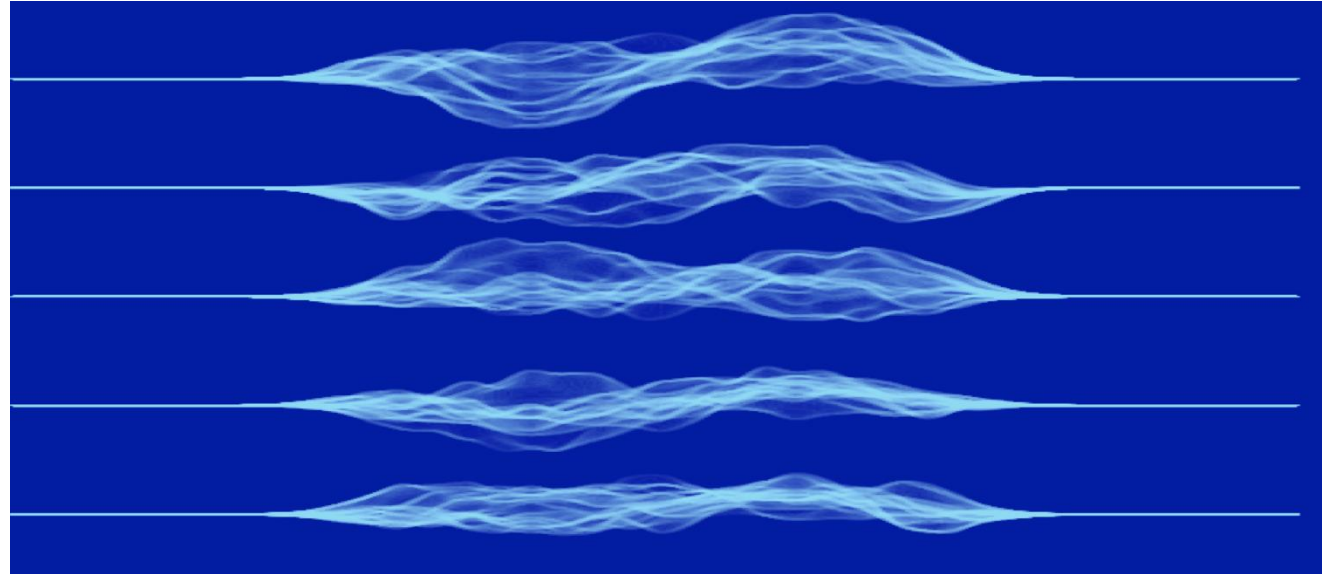


procedural generation of game assets

Procedural generation offers game developers a versatile toolkit for dynamically creating a wide range of assets. These assets encompass everything from lifelike terrain, level layouts, textures, and 3D models to characters, items, and quests.

Who?

...artists and designer using
generative work?



Michael Hansmeyer

Computational Architecture

Michael Hansmeyer, an artist and computational architect, pushes the boundaries of design by blending art and technology.

Known for his innovative use of algorithms, Hansmeyer creates intricate, detailed forms that challenge traditional architectural norms. His work, often described as a fusion of art and science, explores the potential of **computational processes to generate complex, organic structures**.

Through projects like **"Digital Grotesque,"** he demonstrates the transformative power of digital fabrication, producing breathtakingly elaborate environments.

Hansmeyer's pioneering approach not only redefines architectural aesthetics but also opens new horizons for creative expression in the digital age.



Digital Grotesque III

Michael Hansmeyer

Through his 'Digital Grotesque' series, **Michael Hansmeyer** fabricates architectural spaces with the aid of programming, machine learning using **artificial intelligence**, and visual arts, pushing the boundaries of what is possible. Based on purely geometric processes, the team develops what the artists call 'computational architecture'. The latest installment consists of two parts; a **multimedia installation** and an **ornamental column**. The **360-degree video installation** depicts a digital grotto — a cave that '*inhabits a space between artificial and natural*', in endless motion, where spectators can immerse themselves in a constantly changing space generated by detailed, porous, multi-layered structures.



Michael Hansmeyer
Digital Grotesque III

Excerpts from the 360° video installation

Video: Demetris Shammas
Sound: Emiddio Vasquez

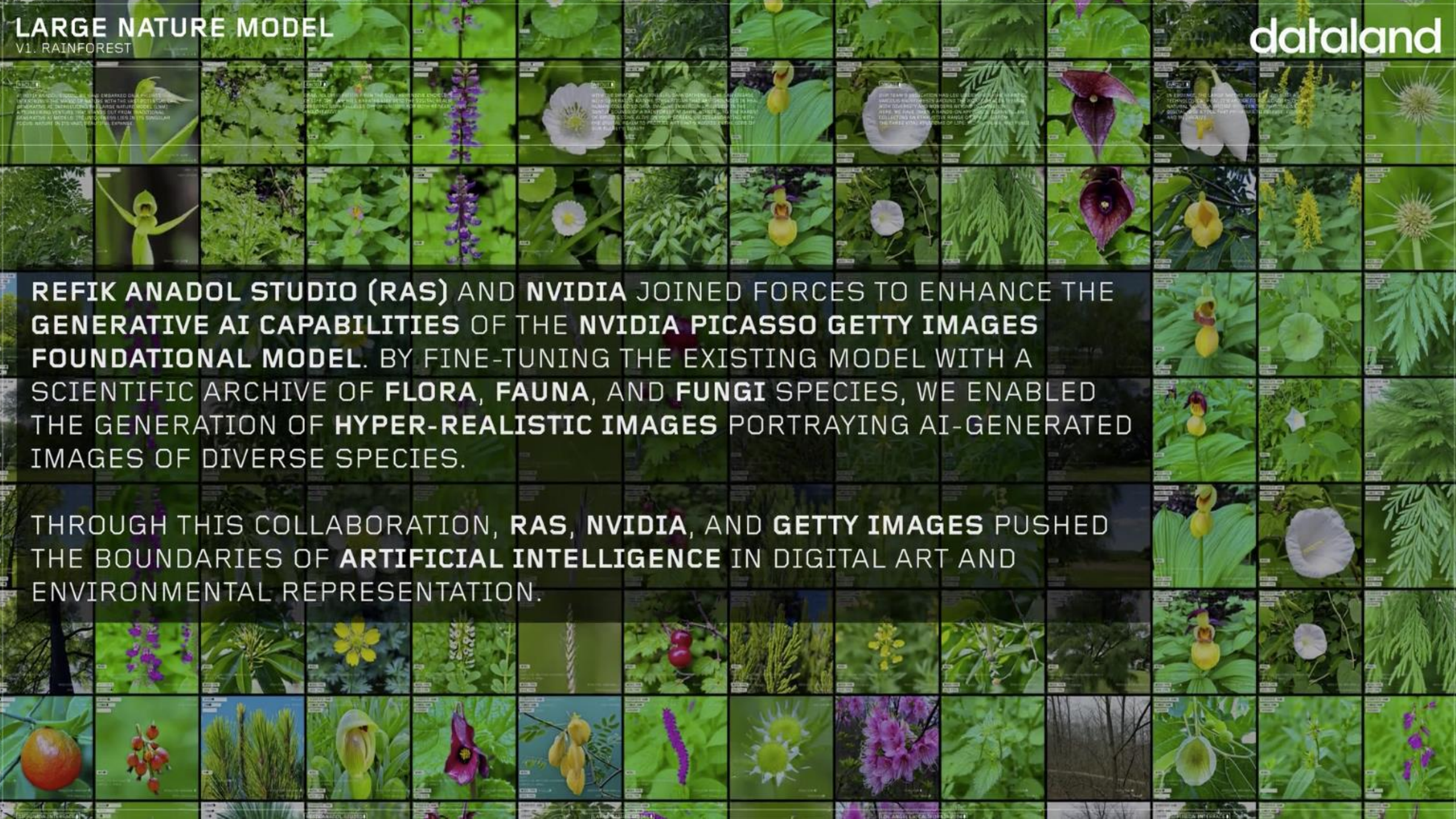
Refik Anadol

Machine Hallucinations abstract Generative Art

Refik Anadol, an artist and computational architect, revolutionises the intersection of art, technology, and spatial design. Utilising **data as his primary medium**, Anadol creates immersive installations that transform physical spaces into dynamic, sensory experiences. His work, characterized by its innovative use of **artificial intelligence and machine learning**, explores **the relationship between digital and physical realities**. Anadol's groundbreaking approach not only redefines the boundaries of digital art but also **offers profound insights into the future of human-machine collaboration in creative expression**.



Refik Anadol Introduces World's First Open-Source Generative AI-Model Dedicated to Nature



LARGE NATURE MODEL

V1. RAINFOREST

dataLand

REFIK ANADOL STUDIO (RAS) AND NVIDIA JOINED FORCES TO ENHANCE THE GENERATIVE AI CAPABILITIES OF THE NVIDIA PICASSO GETTY IMAGES FOUNDATIONAL MODEL. BY FINE-TUNING THE EXISTING MODEL WITH A SCIENTIFIC ARCHIVE OF **FLORA, FAUNA, AND FUNGI** SPECIES, WE ENABLED THE GENERATION OF **HYPER-REALISTIC IMAGES** PORTRAYING AI-GENERATED IMAGES OF DIVERSE SPECIES.

THROUGH THIS COLLABORATION, **RAS, NVIDIA, AND GETTY IMAGES** PUSHED THE BOUNDARIES OF **ARTIFICIAL INTELLIGENCE** IN DIGITAL ART AND ENVIRONMENTAL REPRESENTATION.



Manolo Gamboa Naon

generative artist whose interest focuses on exploring the **digital surface** as a **plastic space** using **code**

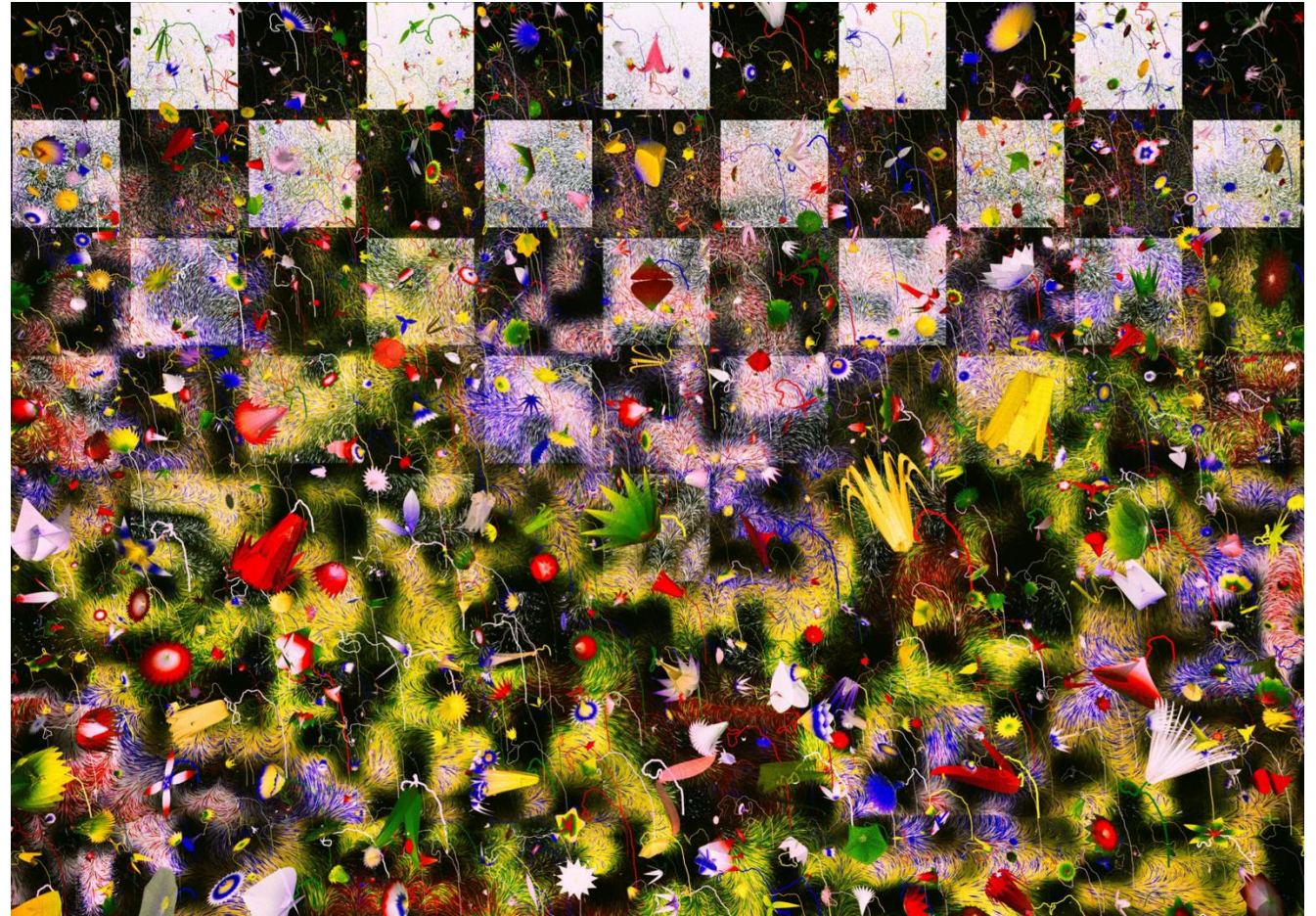
Manolo Gamboa Naon, is a visual artist and creative coder, who captivates audiences with his innovative fusion of art and algorithms. Known for his generative artworks, Naon uses computational processes to create mesmerizing visuals that explore the intersection of geometry, color, and movement. His work, often characterized by its dynamic complexity and organic patterns, pushes the boundaries of digital creativity. By harnessing the power of coding and digital tools, Naon transforms abstract concepts into visually stunning experiences. His pioneering approach not only redefines digital art but also inspires new ways of thinking about the relationship between technology and artistic expression.



88 Allegories

Manoloide (Manolo Gamboa Naon)

'88 Allegories' **generative masterpiece** by Manoloide, a group of 88 individual artworks, collectively engaged together building up one main canvas. Each image holds its meaningful message with flower, colour, number and shape. Each flower is explicitly positioned to add a vibrant visualization to each arrangement. All 88 are displayed as one body of work as one universal message. Again, this is done intuitively to demonstrate and resonate with the natural system of life. The series of 'Allegories 88' is bound to the concept of a 'symbolism' in history of art that allows the viewer not only to interact with work on the visual basis, but also create an intimate bond to the specific details/signs, which have infinite possibilities of interpretation driven by the erudition and imagination of the viewer.



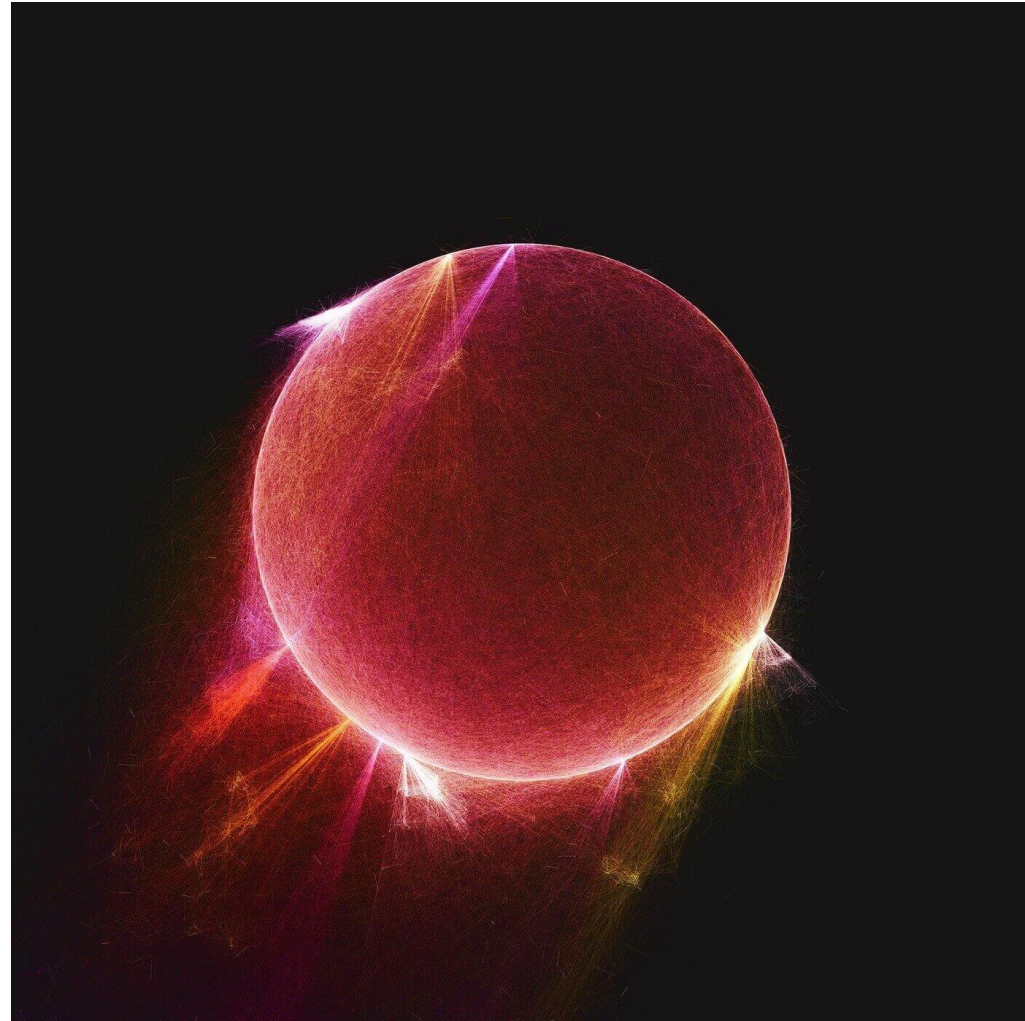
Generative Design and Generative AI

The Future of Creativity **How Generative AI is Revolutionising Art and Design**

synergies and future directions

“Design becomes a dialogue between human intuition and algorithmic evolution.”

Generative design mirrors nature’s capacity for complexity: not imitation, but co-evolution between the natural, digital, and conceptual realms.



Generative art by Anders Hoff. This is part of his project “Inconvergent”, which explores the complex behavior that emerges from systems with simple rules.